PB82-136995

Technical and Economic Evaluation of Mine Closure Procedures

Skelly and Loy
Harrisburg, PA

Prepared for

Bureau of Mines
Washington, DC

Jun 80

U.S. Department of Commerce
National Technical Information Service
NTIS

50272-101

REPORT DOCUMENTATION PAGE

1. REPORT NO. BuMines OFR 153-81

2.

3. Recipient's Accession No. PB82 13699 5

4. Title and Subtitle
Technical and Economic Evaluation of Mine Closure Procedures

5. Report Date
June 1980

6. 348004

7. Author(s)
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8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Skelly and Loy
2601 Front St.
Harrisburg, PA 17110

10. Project/Task/Work Unit No.

11. Contract(C) or Grant(G) No.
(C) J0285030
(G)

12. Sponsoring Organization Name and Address
Office of the Director--Minerals Environmental Technology
Bureau of Mines
U.S. Department of the Interior
Washington, DC 20241

13. Type of Report & Period Covered
Contract research, 9/27/78--6/30/80

14.

15. Supplementary Notes
Approved by the Director, Bureau of Mines, for placement on open file, November 17, 1981.

16. Abstract (Limit: 200 words)

The purpose of this report is to provide industry with a document to aid in the selection of a closure method and to aid government officials in evaluating closure methods that have been used in the past. The types of seals presently in use for numerous engineering environmental and economic parameters were evaluated. A survey of State and Federal regulations pertaining to mine closure is included. Numerous drawings are also included along with several case histories of mine closures.

17. Document Analysis a. Descriptors
Mining
- Mine closure procedures
- Technical and economic evaluation
- Closure methods
- State and Federal regulations
- Seals
- Case histories

b. Identifiers/Open-Ended Terms

c. COSATI Field/Group 08I

18. Availability Statement
Unlimited release by NTIS.

19. Security Class (This Report)

20. Security Class (This Page)

21. No. of Pages
281

22. Price

(See ANSI-Z39.18)

See Instructions on Reverse

OPTIONAL FORM 272 (4-77)
(Formerly NTIS-35)
Department of Commerce

PB82-136995

BuMines OFR 153-81

Technical and Economic Evaluation of MINE CLOSURE PROCEDURES

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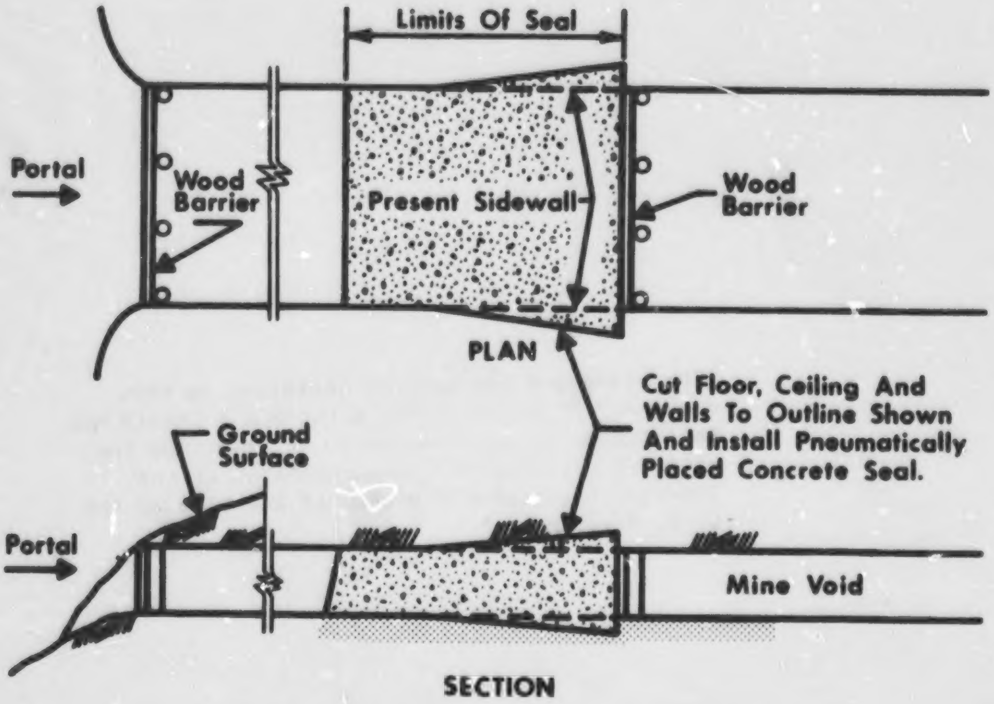
contract #JO285030

final report



Limits Of Seal
Portal
Wood Barrier
Present Sidewall
Wood Barrier
PLAN
Cut Floor, Ceiling And Walls To Outline Shown And Install Pneumatically Placed Concrete Seal.
Ground Surface
Portal
Mine Void
SECTION

Bureau of Mines Open File Report 153-81

REPRODUCED BY
NATIONAL TECHNICAL INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

Submitted to the **UNITED STATES BUREAU OF MINES,** Twin Cities Mining Research Center, Twin Cities, Minnesota, by **SKELLY AND LOY** Engineers-Consultants, Harrisburg, Pennsylvania, June 1980.

"The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or of the U. S. Government."

FOREWARD

This report was prepared by Skelly and Loy, Harrisburg, Pennsylvannia under USBM Contract number J0285030. The contract was initiated under the Minerals Environmental Technology Program. It was administrated under the technical direction of Twin Cities Research Center with Mr. Charles Rhoades acting as Technical Project Officer. Mr. Ronald J. Simonich was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as a part of this contract during the period September 27, 1978 to June 27, 1980. This report was submitted by the authors on June 1980.

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INTRODUCTION AND SUMMARY

Abandoned mines pose a serious threat to public safety and the environment through polluted water discharges and subsidence. Open mine entries, particularily hidden vertical shafts, are a danger to anyone who comes near them and a hazard to both domestic animals and wildlife. Safety hazards are also involved in the improper use of mine closures. These include blowouts and possible flooding from unanticipated water pressure and hazards from gas concentrations.

Past subsidence from underground mines has caused major changes to the surface and groundwater hydrologic regimes, and has resulted in extensive damage to surface structures. Although most subsidence has occured in unpopulated areas, the potential threat from existing workings and those recently abandoned make future subsidence a primary area of concern.

Drainage from both coal and metal mines has caused extensive pollution of surface and groundwater. A 1970 study by the Federal Water Quality Administration estimated that 12,000 miles of streams in the United States were affected by mining-related pollution; 90 percent of which was attributable to coal mining.

This study was conducted to evaluate various mine closure procedures and methods according to their applicability in various engineering, geologic, economic and environmental settings. This compendium of methods is intended to make it easier for a mining company to select a closure procedure compatible with the conditions available at their particular mine.

The study was conducted in two phases. Phase I was a survey of federal and state mine closure regulations and legal liabilities. In Phase II, a literature review was conducted along with an interview survey to obtain closure information and case histories on past and ongoing closure practices for coal and non-coal mines in the United States and other countries.

The results of Phase I indicate both federal and state involvement in underground mine regulations. Of the eight federal agencies involved, the regulations of the Mine Safety and Health Administration, effluent limitations of the Environmental Protection Agency and closure requirements of the Office of Surface Mining apply to all mined lands. The remaining five agencies: U.S. Geological Survey, Bureau of Land Management, U.S. Forest Service, National Park Service and Bureau of Indian Affairs, have jurisdictions limited to federal lands. With the exception of those of the EPA and USGS, federal closure regulations are directed only to coal mines.

Thirty-nine states have underground mining activities. Of the twenty-seven that have regulatory programs, only twenty-three address mine closure as a specific provision in their regulations. As shown on the following summary tables the application of regulations to coal and non-coal mines vary considerably by state. The majority of state closure regulations deal primarily with fencing, covering and posting openings to protect public safety and prevent unauthorized entry. EPA effluent limitations and applicable state water quality standards are included in the regulations of all states.

SUMMARY OF UNDERGROUND MINE CLOSURE REGULATIONS IN MINING STATES

No Closure Regulations	Coal and Non-Coal Regulations	Coal Regulations Only	Non-Coal Regulations Only
Alaska	Alabama	Indiana	Arizona
Arkansas	Colorado	Maryland	California
Iowa	Illinois		Idaho
Louisiana	Kentucky		Kansas
Michigan	Montana		Missouri
Minnesota	Ohio		New Jersey
Georgia	Pennsylvania		New Mexico
Nebraska	Tennessee		New York
Nevada	Utah		Oklahoma
North Carolina	Virginia		Oregon
South Carolina	Washington		Wisconsin
Texas	West Virginia		
Vermont	Wyoming		

SUMMARY OF MINIMUM STATE CLOSURE REQUIREMENTS FOR COAL MINES

Fill, Cap or Other Closure Required	Option of Closure or Fencing	Fence or Protect Against Unauthorized Entry	Posting Required
Illinois	Colorado	Alabama	Alabama
Indiana	Utah	Tennessee	
Maryland	Washington	Virginia	
Ohio	Wyoming		
Pennsylvania			
West Virginia			

SUMMARY OF MINIMUM STATE CLOSURE REQUIREMENTS FOR NON-COAL MINES

Fill Cap or Other Closure Required	Option of Closure or Fencing	Fence or Protect Against Unauthorized Entry	Posting Required
Ohio	Idaho	Alabama	Alabama
Oklahoma	Illinois	Arizona	Arizona
West Virginia	Missouri	California	Colorado
	Montana	Colorado	Idaho
	New Jersey	Kansas	Montana
	New Mexico	Pennsylvania	New Jersey
	New York	Virginia	New Mexico
	Utah		Utah
	Washington		Washington
	Wisconsin		Wisconsin
	Wyoming		

Interviews with state and federal officials revealed no explicit post-closure damage liability statutes. Legal counselors attached to mining and environmental resource agencies and Attorneys General's offices indicate that determining post-closure damage liabilities is a complex issue involving many variables. For long abandoned mines, the problem is compounded by difficulties of identifying the responsible party. Because of the numerous considerations and lack of specific statutes, closure problems are usually resolved on a case by case basis only after conducting case law research. The common law theories of negligence, negligence per se, nuisance, subjacent or lateral support with strict liability and breach of contract are generally applied.

In response to requirements for water quality and subsidence control, a variety of closure methods have been developed over the years.

These closure methods can be divided into two categories: primary closure technology, and technology developed for facilitating closure. Primary closure techniques include air seals, dry seals, hydraulic seals and temporary barriers. Because of reported failures and inherent inefficencies of sealing methods, slurry trenches, alkaline regrading and discharge treatment either in lieu of or in conjunction with seals, are often the only feasible solution to mine drainage problems. Other techniques, such as infiltration control and subsidence control, performed either during or after mining, can lessen the magnitude of mine drainage and subsidence problems that must be dealt with by seals and other primary methods.

Over 100 references and 281 phone interviews were made to obtain information in case histories of coal and non-coal mine closures. From this effort, 59 case histories of coal mine closures were reviewed and listed according to the geologic conditions involved, type of operation, type of seal, effectiveness of water pollution control and other pertinent considerations. The survey found that few case studies are available for non-coal mines, apparently because water quality and other off-site problems have not been as significant as those of coal mines. The case histories found for non-coal mines indicated that they were sealed primarily to protect public safety.

Most non-coal mine closures are undertaken as a response to market conditions, i.e., either the market price falls to an uneconomical level, or the grade of ore being mined falls to an uneconomical level. Therefore, with the possibility of a regeneration of mining activities always present, non-coal mine closures are "temporary" in nature, consisting of either uncompacted fill in entryways or the use of fences and "posting" to warn persons approaching the mine that they are on private and possibly dangerous property.

The regulations covering this type of "temporary" sealing range from very definite restrictions as to the type and size of materials for fencing, down to the use of terms such as "properly" or "effectively" sealed mines, "properly" or "effectively" usually being assessed by a regulatory agency.

Another factor that makes the closure of non-coal mines more of a safety consideration than an environmental one is that the geologic conditions surrounding the formation of minerals other than coal do not normally generate undesirable side effects such as acid mine drainage after the mine is depleted.

Consequently, even in a case of "permanent" closure of a non-coal mine, the usual procedure is to install a thin (10"±), reinforced concrete "seal", which effectively blocks entry into the mine by persons or animals.

The exception to this would be vertical shafts, which are completely backfilled and capped off with a reinforced concrete seal keyed into the surrounding rock strata, to totally preclude subsidence in the shaft area.

From the case studies reviewed, it appears that the success or failure of specific closure procedures is tied primarily to the physical conditions of the mine and the adequacy of the design theory. A hydraulic seal may work as expected in solid rock but fails badly when installed in unstable strata. Air seals, theoretically designed to cut off oxygen and hence the formation of acid water in the mine, fail because of most mine's "breathing" characteristics through fractured rock strata in response to changes in outside atmospheric pressure. Thus, previously air sealed mines often require treatment facilities to maintain environmental quality. In view of these examples, technical and design considerations for each seal type are summarized and listed for insight in selecting the appropriate closure method and predicting its effectiveness.

The following sections of this report document the methodology, findings, conclusions and recommendations generated as a result of this study.

CONCLUSIONS

For this study, documents were reviewed and personal contacts were made with industry and governmental officials to obtain information and closure regulations and evaluate problems associated with closure of underground mines — mine water drainage, subsidence, and safety. Initial study efforts identified the legal obligations and the regulatory agencies involved in closure procedures for the mining industry in the United States. Subsequent tasks further identified and evaluated the effectiveness of current pre- and post-closure technology from actual case histories. From this work, the following conclusions have been drawn:

- Current state and federal regulatory involvment concerns itself primarily with closure methods, safety and effluent requirements, with little or no attention focused on subsidence control and liabilities.
- Determining post-closure damage liabilities with respect to mine drainage, safety and subsidence is a complex issue involving numerous variables. Specific problems are usually resolved on a case by case basis only after conducting case law research.
- A significant legal/regulatory question in both coal and non-coal segments of the underground mining industries is the responsibility for maintenance of environmental quality after closure — who is responsible for post-closure water quality degradation and subsidence under the existing laws, which generally are not specific on this matter.
- Seals placed in entries for most metal/nonmetal mines are often only "temporary" in nature, since market fluctuations can call for mines to reopen at times to recover lower grade ores, made cost effective by higher returns. Closure of these mines is often accomplished by only fencing.

- Fossil fuels mines usually deplete their reserves before abandonment and closure, mandating more "permanent" sealing procedures.

- The state of the art of mine sealing is best reflected by the coal industry, since more permanent sealing procedures are generally required to close underground coal mines. Mine closure methods presently involve the construction or establishment of one or more types of air, dry or hydraulic seals or blockages for the shafts, boreholes, slopes or drift entries to underground mines.

- The most comprehensive documentation of coal mine closure efforts deals with sealing of long-abandoned underground mines, rather than recently closing ones, although technology is quite similar in both situations.

- Sealing of abandoned coal mines was studied and demonstrated intensively and widely in the late 1960's and early 1970's. For numerous reasons — limited success of many demonstrations, reallocations of demonstration funding, secondary problems relating to property ownership and potential sterilization of reserves, and the lack of any novel new closure technology — mine closure demonstration and documentation efforts have been on the decline.

- The effectiveness of each seal is dependent on several inherent or anticipated features of the mine, such as the geologic character of the overburden and the hydrologic setting of the mine area. Economics and the availability of materials are also contributing factors to consider.

- Sealing to achieve mine inundation has to date seen limited success and application, partly because of the complexity to achieve watertight seal when coal barriers are thin or fractured and when overburden roof rock is fractured or faulted.

- Limited success mentioned above combined with environmental/economic impacts of potential seal leakage of mine waters and potential for massive seal failure with resultant health and safety hazards have reduced application of mine sealing technology where inundation would be a by-product.

- Many underground mining operations are plagued with the problem of controlling, handling or treating water entering the mine. Both ground and surface water may enter the mine through geologic formations or features inherent to the site or through mine entries or boreholes to the surface. Several practices are presently employed which either 1) prevent water from entering the mine or 2) plan the mining scheme to allow for water influxes and employ special water handling techniques or control measures to protect or improve the quality before it is treated. Such measures include preplanned or selective underground pumping, premining analysis to determine optimum sump locations, and underground treatment.

- Case history data pertaining to pre- and post-closure procedures and site specific applications are abundant for the coal mines of Northern Appalachia, but are few for non-coal and underground coal mines elsewhere in the United States.

- Subsidence over mined out areas is usually anticipated, but its rate and intensity are not often predictable. Recent mine designs have planned subsidence over large areas which hopefully will eliminate settling problems in the future. In more localized areas where subsidence control is essential, various supportive structures involving some sort of timbering, grouting and/or backfilling with waste materials can be employed.

- Major emphasis in the closure cases that could be documented focused on water quality. Post-closure procedures did not always deal directly with safety problems but were usually designed to prevent people and animals from entering the mine.

- Non-existent, incomplete or inconsistent reported water quality data has thwarted efforts to document actual pollution abatement potential of sealed versus unsealed mines on effluent quality.

- Eighty percent of those cases where before and after water sampling data were available showed improved water quality, most probably due to reduced acid production from inundated acid forming materials.

RECOMMENDATIONS

In light of previously presented conclusions, a number of pertinent recommendations have been generated:

- Hydraulic seals can be defeated (potentially as a disaster) by leakage, piping and subsequent failure of the seal itself or the adjacent coal or overburden (roof rock) strata. Thus, an evaluation of future land use activities in the area above and contiguous to the proposed mine seals is imperative to permit assessment of potential for any unexpected increase of hydrostatic head in the mine pool due to increased infiltration from activities such as surface mining.

- If the mine workings are accessible, controlled flushing to prevent future surface subsidence should be investigated prior to installing expensive seals.

- Even inundation of mine workings behind hydraulic seals upon closure does not assure to the elimination of pollution. Groundwater pollution can occur miles from the sealed complex. The increased cost of treating water supply sources contaminated by the water in the sealed mine pool to potable standards could outweigh the cost of constructing and operating an AMD plant for surface water discharge.

- According to the data reviewed, sealing only has positive results when applied to an entire complex. Attempts to seal selected openings should be carefully studied for overall effectiveness and potential discharges that may result in other openings from the pooled water.

The case histories reviewed in this report have dealt primarily with the problem of sealing abandoned workings, because those situations have been most thoroughly documented. It is appropriate, however, to also address future mining activities that may contribute to environmental problems.

From the case studies, the following recommendations could help minimize these problems from future underground mining:

- Location of drifts, shafts and entries in firm surrounding strata and maintenance of adequately-sized coal barriers should be major objectives in pre-mine planning.

- Downdip mining should be universally adopted wherever potential water pollution could occur.

In addition to the aforementioned recommendations, which can be put into practice with current technology, there is an obvious need for research and development for improving mine sealing. Presented below are some of the areas where future efforts might be directed.

- Available documents and case history information primarily describe mine sealing programs for underground coal mines in the Eastern coalfields of the United States. More specific non-coal case history information is needed for future evaluation of mine closure procedures' effectiveness under varied geologic distribution. This is not a collection recommendation — such information must be generated as mines are actually being closed.

- Where case histories are available there is generally a lack of continuity in reporting testing procedures and results from one report or agency to another. Standardization of the testing programs between sites would greatly enhance the interpretation of results.

- For each of the different air, dry and hydraulic seals evaluated in this study, the foremost problem facing the effectiveness of the seal is the integrity of the strata into which the seal is tied. More effective measures or design criteria are needed to control or prevent seal failure due to leakage or decomposition of the surrounding rock strata.

- An effort should be made to accurately map mineral barriers for inspection by the appropriate regulatory agencies to prevent barrier failure from subsequent sealing and inundation.

- High priority should be given to the development of a highly "plastic" grout. Such a grout should retain its resealing characteristics for long periods of time, resist flushing under imposed hydrologic heads, and not allow the seal to crush under roof pressure.
- A means of static or bench-mark sensing should be developed to permit rapid inspection of seal shifting as a predictor of leakage or failure.
- Special maintenance equipment such as a "grout truck" should be investigated to minimize maintenance costs, thereby encouraging regular maintenance.
- Temporary seals such as a permeable limestone barrier with a lime injection system should be developed for sealing active mine complexes.
- The development of temporary, economical and reusable seals such as "Hypalon" water bags should be pursued for active complexes.

As pointed out throughout this report, numerous studies on mine sealing have been completed over the past years. While these studies have served their intended purpose, they have not been widely disseminated to the industry who must deal with closure problems. It is, therefore, the final recommendation of this report to encourage dissemination of the data available so that mine operators can make an educated decision on their approach to sealing projects. Because of the vast amount of data, it is suggested that an informational brochure be developed and distributed for mine seals and closure techniques. The brochure if well illustrated and succinct can give operators a guide to closure methods and provide a reference to pursue more detailed information.

Prior to development of such a brochure, it would be appropriate to establish and maintain a "data library" containing all of the information currently available on current and past mine closure procedures and activities. As this study revealed, there is a wealth of information available, even if its scope is largely limited to coal, but it is widely scattered and not easily evaluated on a comparative basis. The study performed here went far toward locating and assembling much of the information referenced above, but in reality, the percentage of available detail that was evaluated and presented within the scope of this study was relatively small. The tremendous amount of detailed information that is available would be of much greater value if maintained in a single, well indexed and documented data base.

MINE CLOSURE REQUIREMENTS AND LIABILITIES

This section documents the bulk of this study's Phase I efforts and findings. These efforts were essentially directed toward the development of the legal criteria and liabilities pertaining to closure of underground coal, metal, and nonmetal mines across the nation.

MINE CLOSURE REGULATIONS

As shown on Table 1, thirty-nine (39) states have underground mining activities. One of the initial study tasks during the first phase of activity therefore was a reveiw of federal and state laws relating to underground mine closure requirements and liabilities in these states. The text and tables presented in the following pages document those federal and state laws and regulations in existence during Phase I of this study that impact closure of active underground mining operations. State coal mining and reclamation regulations that are presently being revised or developed to meet the standards of the OSM federal regulatory program were not included. These regulations, which cover the surface effects of underground mines, are required by all coal mining activities, will receive final approval by January 1981.

Federal Level Regulations

Analysis of regulatory and jurisdictional responsibilities revealed that there are eight federal agencies that are involved at either nationwide

TABLE 1. - Minerals mined using underground techniques by state.

STATE	FOSSIL FUELS		FERROUS MINERALS				NONFERROUS MINERALS										NONMETALLIC MINERALS																OTHER *
	COAL	OIL SHALE	IRON ORE	MOLYBDENUM ORES	TUNGSTEN ORES	VANADIUM ORES	ANTIMONY	BAUXITE (ALUMINUM)	CINNABAR (MERCURY)	COPPER ORES	GALENA (LEAD)	GOLD	PLATINUM ORES	SPHALERITE (ZINC, CADMIUM)	SILVER	URANIUM ORES	BARITE	BORATE MINERALS	CHRYSOTILE (ASBESTOS)	CLAYS	FLUORSPAR	GEM STONES	GYPSUM	LIMESTONE	PERLITE	PHOSPHATES	POTASH	SALT	SANDSTONE	TALC	TRONA	WOLLASTONITE	
ALABAMA	●																							●									
ALASKA					●							●																					
ARIZONA									●	●	●	●		●	●	●			●		●							●	●				●
ARKANSAS																								●									
CALIFORNIA		●	●	●	●				●	●	●	●	●	●	●			●		●	●									●			
COLORADO	●	●		●	●	●				●	●	●		●	●	●				●													●
CONNECTICUT																																	
DELAWARE																																	
FLORIDA																																	
GEORGIA																								●									
HAWAII																																	
IDAHO				●	●		●			●	●	●	●	●	●	●					●	●				●							●
ILLINOIS	●										●			●							●								●				

* INCLUDES: FELDSPAR - ARIZONA, CASSITERITE - COLORADO, COBALT - NICKEL - THORIUM - IDAHO, TELLURIUM - NEW MEXICO

TABLE 1. - Minerals mined using underground techniques by state - (Cont'd.)

STATE	FOSSIL FUELS		FERROUS MINERALS				NONFERROUS MINERALS										NONMETALLIC MINERALS																
	COAL	OIL SHALE	IRON ORE	MOLYBDENUM ORES	TUNGSTEN ORES	VANADIUM ORES	ANTIMONY	BAUXITE (ALUMINUM)	CINNABAR (MERCURY)	COPPER ORES	GALENA (LEAD)	GOLD	PLATINUM ORES	SPHALERITE (ZINC, CADMIUM)	SILVER	URANIUM ORES	BARITE	BORATE MINERALS	CHRYSOTILE (ASBESTOS)	CLAYS	FLUORSPAR	GEM STONES	GYPSUM	LIMESTONE	PERLITE	PHOSPHATES	POTASH	SALT	SANDSTONE	TALC	TRONA	WOLLASTONITE	OTHER*
INDIANA	●																						●	●									
IOWA	●																						●										
KANSAS																							●	●				●					
KENTUCKY	●										●			●						●	●			●									
LOUISIANA																												●					
MAINE																																	
MARYLAND	●																																
MASSACHUSETTS																																	
MICHIGAN			●							●					●								●					●					
MINNESOTA			●																									●					
MISSISSIPPI																																	
MISSOURI			●							●	●			●	●											●							
MONTANA	●									●		●		●	●	●	●													●			

* INCLUDES: FELDSPAR - ARIZONA, CASSITERITE - COLORADO, COBALT - NICKEL - THORIUM - IDAHO, TELLURIUM - NEW MEXICO

TABLE 1. - Minerals mined using underground techniques by state - (Cont'd.)

STATE	FOSSIL FUELS		FERROUS MINERALS				NONFERROUS MINERALS										NONMETALLIC MINERALS																
	COAL	OIL SHALE	IRON ORE	MOLYBDENUM ORES	TUNGSTEN ORES	VANADIUM ORES	ANTIMONY	BAUXITE (ALUMINUM)	CINNABAR (MERCURY)	COPPER ORES	GALENA (LEAD)	GOLD	PLATINUM ORES	SPHALERITE (ZINC, CADMIUM)	SILVER	URANIUM ORES	BARITE	BORATE MINERALS	CHRYSOTILE (ASBESTOS)	CLAYS	FLUORSPAR	GEM STONES	GYPSUM	LIMESTONE	PERLITE	PHOSPHATES	POTASH	SALT	SANDSTONE	TALC	TRONA	WOLLASTONITE	OTHER*
NEBRASKA																								●									
NEVADA					●				●	●	●	●		●	●					●	●	●			●								
NEW HAMPSHIRE																																	
NEW JERSEY														●																			
NEW MEXICO				●						●	●	●		●	●	●					●						●	●					●
NEW YORK														●								●	●					●		●		●	
NORTH CAROLINA																														●			
NORTH DAKOTA																																	
OHIO	●																							●				●					
OKLAHOMA																								●									
OREGON					●					●		●			●																		
PENNSYLVANIA	●		●								●			●						●				●									
RHODE ISLAND																																	

* INCLUDES: FELDSPAR - ARIZONA, CASSITERITE - COLORADO, COBALT - NICKEL - THORIUM - IDAHO, TELLURIUM - NEW MEXICO

TABLE 1. - Minerals mined using underground techniques by state - (Cont'd.)

STATE	FOSSIL FUELS		FERROUS MINERALS				NONFERROUS MINERALS										NONMETALLIC MINERALS																
	COAL	OIL SHALE	IRON ORE	MOLYBDENUM ORES	TUNGSTEN ORES	VANADIUM ORES	ANTIMONY	BAUXITE (ALUMINUM)	CINNABAR (MERCURY)	COPPER ORES	GALENA (LEAD)	GOLD	PLATINUM ORES	SPHALERITE (ZINC, CADMIUM)	SILVER	URANIUM ORES	BARITE	BORATE MINERALS	CHRYSOTILE (ASBESTOS)	CLAYS	FLUORSPAR	GEM STONES	GYPSUM	LIMESTONE	PERLITE	PHOSPHATES	POTASH	SALT	SANDSTONE	TALC	TRONA	WOLLASTONITE	OTHER *
SOUTH CAROLINA																																	
SOUTH DAKOTA												●																					
TENNESSEE	●									●				●																			
TEXAS																								●				●					
UTAH	●									●	●			●	●	●														●			●
VERMONT																														●			
VIRGINIA	●									●	●			●	●								●										●
WASHINGTON	●			●						●	●	●		●	●	●																	
WEST VIRGINIA	●																			●				●				●	●				
WISCONSIN										●	●			●															●				
WYOMING	●		●													●															●		

* INCLUDES: FELDSPAR - ARIZONA, CASSITERITE - COLORADO, COBALT - NICKEL - THORIUM - IDAHO, TELLURIUM - NEW MEXICO.

or at some lesser jurisdictional level in the regulation of underground mining and mine closure activities. Those agencies and their general areas of jurisdiction are summarized in Table 2. As the table shows, only two of the eight agencies — MSHA (health and safety regulations) and EPA (effluent limitations) regulate on a nationwide basis. Of these, EPA's effluent regulatory requirements are by far the most complex, and are as a result discussed independently in the following pages. MSHA and the other federal regulatory agencies have mine closure guidelines which are much more simply understood and are, thus, primarily summarized in tabular format.

Effluent Limitations

EPA's effluent limitations for the various underground mining categories are presented in Table 3. These limitations apply to point source discharges from active mines (both surface and underground), which are regulated through the National Pollutant Dishcarge Elimination System (NPDES) permit. It should be noted here for clarification purposes, that EPA is not the sole agency in the nation regulating the quality of underground mine discharges. Some individual states have also enacted effluent limitations which must be considered, as well as water quality standards which can be substantially more stringent then the regulatory requirements summarized here. However, these water quality standards are: 1) most frequently established based on existing and/or projected water uses; 2) promulgated individually for each watershed or drainage basin regulated; and 3) vary as a result of 1) and 2) on a watershed by

TABLE 2. - Federal agency general jurisdictional authority.

JURISDICTIONAL AUTHORITY	FEDERAL AGENCIES*							
	MSHA	OSM	USGS	BLM	USFS	NPS	BIA	EPA
STATE OR PRIVATELY OWNED NON-COAL ESTATES	●							●
STATE OR PRIVATELY OWNED COAL ESTATES	●	●						●
ALL FEDERALLY OWNED NON-COAL ESTATES	●		●	●				●
ALL FEDERALLY OWNED COAL ESTATES	●	●	●	●				●
NATIONAL FOREST LAND (NON-COAL MINING)	●		●	●	●			●
NATIONAL FOREST LAND (COAL MINING)	●	●	●	●	●			●
NATIONAL PARK LAND (NON-COAL MINING)	●		●	●		●		●
NATIONAL PARK LAND (COAL MINING)	●	●	●	●		●		●
INDIAN LAND (NON-COAL MINING)	●		●	●			●	●
INDIAN LAND (COAL MINING)	●	●	●	●			●	●

* MSHA: Mine Safety and Health Administration
OSM: Office of Surface Mining
USGS: United States Geological Survey
BLM: Bureau of Land Management
USFS: United States Forest Service
NPS: National Park Service
BIA: Bureau of Indian Affairs
EPA: Environmental Protection Agency

TABLE 3. - Federal EPA effluent

MINING CATEGORY		EFFLUENT CHARACTERISTICS (mg/l)[1]												
		pH	TSS		Fe (total)		Fe (dissolved)		Mn		Al		Cu	
		Range	Max.[3]	Avg.[4]	Max.[3]	Avg.[4]	Max.[3]	Avg.[4]	Max.[3]	Avg.[4]	Max.[3]	Avg.[4]	Max.[3]	Avg.[4]
COAL MINING	Acid or Ferruginous Mine Drainage[5] (BPT)	6-9*	70.0**	35.0**	7.0	3.5			4.0	2.0				
	Alkaline Mine Drainage[6] (BPT)	6-9	70.0**	35.0**	7.0	3.5								
	Acid or Ferruginous Mine Drainage[5] (new sources)	6-9*	70.0**	35.0**	6.0	3.0			4.0	2.0				
	Alkaline Mine Drainage[6] (new sources)	6-9	70.0**	35.0**	6.0	3.0								
MINERAL MINING	Crushed Stone (BPT)	6-9†	45	25										
	Phosphate Rock (BPT)	6-9	60	30										
	Phosphate Rock (new sources)	6-9	60	30										
ORE MINING	Iron Ore (BPT)	6-9††	30	20			2.0	1.0						
	Base and Precious Metals[7] (BPT)	6-9††	30	20									0.30	0.15
	Aluminum Ore (BPT)	6-9††	30	20	1.0	0.5					2.0	1.0		
	Ferroalloy Ores[8] (BPT for mines producing ≥ 5,000 metric tons)	6-9††	30	20									0.3	0.15
	Ferroalloy Ores[8] (BPT for mines producing) < 5,000 metric tons)	6-9††	50	30										
	Uranium, Radium and Vanadium Ores[9] (BPT)	6-9††	30	20										
	Mercury Ore (BPT)	6-9††	30	20										

FOOT NOTES:

[1] Numerical values are expressed exactly as they appear in source documents.

[2] Values in picocuries per liter (pCi/l).

[3] Maximum for any 1 day.

[4] Average of daily values for 30 consecutive days.

[5] Acid or ferruginous mine drainage means mine drainage which before any treatment either has a pH of less than 6.0 or a total iron concentration of more than 10 mg/l.

[6] Alkaline mine drainage means mine drainage which before any treatment has a pH of more than 6.0 and a total iron concentration of less than 10 mg/l.

[7] Included are copper bearing, lead bearing, zinc bearing, gold bearing, or silver bearing ores; also any combination of these ores.

[8] Included are chromium, cobalt, columbium, tantalum, manganese, molybdenum, nickel, tungsten, and vanadium (recovered alone and not as a by-product of uranium mining).

[9] Only vanadium by-product production from uranium ores is covered.

limitations by mining category.

EFFLUENT CHARACTERISTICS (mg/l)[1]																			
Zn		Pb		Ni		Hg		Cd		As		Ra 226[2] (dissolved)		Ra 226[2] (total)		U		COD	
Max.[3]	Avg.[4]	Max.[3]	Avg.[4]	Max.[3]	Avg.[4]	Max.[3]	Avg.[4]	Max.[3]	Avg.[4]	Max.[3]	Avg.[4]	Max.[3]	Avg.[4]	Max.[3]	Avg.[4]	Max.[3]	Avg.[4]	Max.[3]	Avg.[4]
1.5	0.75	0.6	0.3			0.002	0.001												
1.0	0.5	0.6	0.3					0.10	0.05	1.0	0.5								
1.0	0.5											10	3	30	10	4	2	200	100
				0.2	0.1	0.002	0.001												

*Where the application of neutralization and sedimentation treatment technology results in an inability to comply with manganese limitations, the permit issuer may allow the pH level to be exceeded to a small extent in order to achieve manganese limitations.

**These TSS limitations shall not apply to discharges from coal mines located in the following States: Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming; in these States, TSS limitations shall be determined on a case-by-case basis.

†In the case of discharge into receiving waters for which the pH, if unaltered by man's activities, is or would be less than 6.0 and water quality criteria in water quality standards authorize such lower pH, the pH limitation for such discharge may be adjusted downward to the pH water quality criterion for the receiving waters. In no case shall a pH limitation outside the range 5.0 to 9.0 be permitted.

††Where the application of neutralization and sedimentation treatment technology results in inability to comply with the pH limitations, the permit issuer may allow the pH level in the final effluent to be exceeded to a small extent in order that the other effluent limitations in the permit will be achieved. In no case shall the pH of the final effluent exceed 9.5. In the case of a discharge into natural receiving waters for which the pH, if unaltered by man's activities, is or would be less than 6.0 and approved water quality standards authorize such lower pH, the pH limitations for the discharge may be adjusted downward to the pH water quality criterion for the receiving waters provided the other effluent limitations for the discharge are met. In no case shall a pH limitation below 5.0 be permitted.

watershed basis. Thus, in all cases, EPA's effluent limitations must be met at a minimum, but in order to meet state effluent limitations and water quality standards in specific areas, much more stringent effluent quality control is sometimes required on the part of the mining industry.

Analysis and summarization of all of the underground mining state's water quality standards on an individual watershed basis was obviously beyond the scope of this study. Only the Federal EPA effluent limitations are presented here, with the caution that, depending on state effluent limitations and water quality standards, even more stringent limitations might, in reality, be in effect in specific areas. In practice, the effluent limitations listed in following pages, in conjunction with applicable state water quality standards, are generally used in the NPDES permit process for discharges emanating from underground mines. These discharge limitations apply not only during the life of the facility, but may also apply upon closure. It should be noted that the effluent guidelines themselves apply to active underground mines, while the NPDES permit requirements may also apply to those mines after closure. This latter determination is based on whether the mine discharge is considered a point source and on the judgement of the EPA regional officer or state officer administering the NPDES program. Along those lines, the states that are currently administering their own NPDES programs are listed on the following page.

California
Colorado
Connecticut
Delaware
Georgia
Hawaii
Illinois
Indiana
Iowa
Kansas
Maryland
Michigan
Minnesota
Mississippi
Missouri
Montana
Nebraska
Nevada
New York
North Carolina
North Dakota
Ohio
Oregon
Pennsylvania
South Carolina
Tennessee
Vermont
Virginia
Washington
Wisconsin
Wyoming

In reviewing Table 3, a number of points should be noted:

- Effluent guidelines are given for only those minerals extracted by underground mining techniques.

- BPT is "best practicable control technology" which is currently available. BPT effluent standards are defined as the average effluent quality of the best existing treatment facilities in a specific industry. Considerations are also given to:

  1) the total cost of applications of technology in relation to the effluent reduction benefits to be achieved from such application;

  2) the size and age of equipment and facilities involved;

  3) the processes employed

  4) the engineering aspects of the application of various types of control techniques;

5) process changes;

6) non-water quality environmental impact (including energy requirements).

BPT emphasizes treatment facilities at the end of the manufacturing process itself, but includes the control technologies within the process itself, when the latter are considered to be normal practices within an industry.

- New source standards apply to treatment facilities which were constructed after the effective date of the BPT standards (which varies by industry). New source standards are based upon effluents achievable using best available demonstrated methods and improved production processes. Consideration must also be given to:

  1) the type of process employed and process changes;

  2) operating methods;

  3) batch as opposed to continuous operations;

  4) use of alternative raw materials and mixes of raw materials;

  5) use of dry rather than wet processes;

  6) recovery of pollutants as by-products.

- A mine classified as "existing" may be subsequently reclassified as "new", and fall under "new source" standards, if it undergoes a "major alteration". This determination will be made by EPA on a case-by-case basis, and normal activities, such as expansion or acquisition of additional land or mineral rights will not be determinative. Any treatment plant overflow beyond normal discharge rates is not subject to the limitations presented in the table if the facilities are designed, constructed, and maintained to contain or treat the volume of effluent which would result from a 10 year, 24 hour precipitation event for the area of the plant.

The (BPT) standards shown in the coal mine portion of the EPA table are final standards, and became effective on April 26, 1977. The (new sources) standards are also final, applying to those new coal mines receiving a MSHA identification number after the effective date of February 13, 1979. Effluent standards for Subpart E, "Areas Under Reclamation", as presently reserved due to the lack of sufficient information to justify imposition of standards for inactive or abandoned mines. The EPA plans to investigate the problem of post-mining discharges, and possibly promulgate standards to regulate these discharges, in a timely manner. The Commonwealth of Pennsylvania has instigated a lawsuit, presently in the courts, to require the EPA to promulgate Subpart "E" standards.

The mineral mining portion of the Federal EPA Effluent Limitations Table also shows final (BPT) standards, which were published on July 12, 1977. These were published for five mining subcategories, only two of which are mined by underground methods — crushed stone and phosphate rock which are presented in the table. These standards were followed, on March 10, 1978, with (new sources) performance standards for phosphate rock mining, which were also shown in the table.

All other mineral categories defined in Table 1 but not shown in Table 3 have interim effluent standards which only apply to the processing segment of that mineral industry. In these cases, no formal effluent limitations have been set for the mining segments of the industries, and limitations that do exist are case-specific and set accordingly to the best engineering judgment of EPA's regional officer.

The effluent limitations presented in the ore mining portion of the EPA Table are final (BPT) standards effective as of July 11, 1978.

Closure Regulations

Table 4 presents, in summary form, the regulations of the seven federal agencies that potentially impact the closure of underground mines. Prior to analysis of the tabulated information, a number of important factors should be considered:

- The numbers found in parenthesis at the end of each information entry refer to the source of that specific entry. Those sources are listed and numbered on the left-hand page in the column entitled "Title of Regulations". Where the specific information entry states "No Specific Mention", the following numbers in parenthesis refer to the regulations which were reviewed.
- Many of the agencies also regulate or specify effluent limitations, but those limitations in most cases duplicate the previously discussed EPA effluent limitations.
- Federal leases, permits, and licenses may also stipulate further or more stringent conditions to be met on a case-by-case basis, according to those federal agencies' technical and environmental analyses of the areas in question.
- The USGS coal regulations state that, by determination of the Secretary of the Interior, if a federal coal estate lies in a state with laws or regulations at least as stringent as federal regulations, enforcement of those state laws may be mandated for the Federal coal estate. Along these lines, there are currently six states —Wyoming, Utah, New Mexico, North Dakota, Montana, and Colorado — which presently have some appropriate regulations which apply to federal coal estates within their boundaries. Although these are surface coal mining land reclamation statutes, they may also regulate the surface effects of underground mining activity.

- One of the more unique regulations, presented in this summary table, is the one found in the Office of Surface Mining statutes part 817.50, which requires that all drift mine openings located in acid or iron producing strata be constructed in such a manner as to prevent any gravity discharges. This would require the use of down-dip mining.

It is interesting to note, upon review of this table that even federal agencies' regulations do not, for the most part, specify mine closure requirements. The reason for this situation depends upon the significant differences between coal and non-coal mining markets and mining strategies. The coal market is such that, with few exceptions, an underground coal mine, once opened, is generally mined continuously until the available mineral reserve is depleted. Closure of the coal mine is, therefore, most often a permanent operation. The markets of many non-coal mining industries, however, fluctuate more and determine the grades of mineral that are economically minable. A non-coal mine generally closes because the grade of the material being mined drops below currently economically recoverable levels, not because that mineral is exhausted. Months or years later, however, as the value of that non-coal commodity rises, it may become economical to mine and market the lower grade mineral that could not be mined earlier. As a result of this fact, non-coal mines have a much higher frequency of "opening" and "closing" and are generally considered only "temporarily closed", pending an improvement in commodity market economics relative to the grade of mineral within the mine. For these reasons, closure of these non-coal mines has been more loosely regulated, since implementation of costly or complex closure procedures would only complicate subsequent mine reopening.

TABLE 4. - Federal regulations related

FEDERAL REGULATORY AGENCY	TITLE OF REGULATIONS	JURISDICTIONAL AUTHORITY	CLOSURE METHODS	
			COAL	NON-COAL
Department of Labor, Mine Safety and Health Administration	30 CFR Mineral Resources; Chapter I; Part 75 - Mandatory Safety Standards - Underground Coal Mines (1); Part 57 - Health and Safety Standards - Metal and Nonmetallic Underground Mines (2)	All Mines: · Apply to all underground operations, whether mineral estate is Federal, state, or privately owned.	· Seal all openings as prescribed by regulatory authority. (1) - Cap or fill shaft openings: filling to be for entire depth, with first 50 feet from bottom of coalbed filled with incombustible material; capping to be 6 inch thick concrete cap or equivalent with vent pipe (≥ 2 inches in diameter) extending ≥ 15 feet above surface of shaft. - Seal slope or drift openings with solid, substantial, incombustible material such as concrete blocks, bricks, or tile, or completely fill with incombustible material for at least 25 feet into such openings.	· No specific mention. (2)
Department of the Interior, Office of Surface Mining Reclamation and Enforcement	Proposed Rules for Permanent Regulatory Program (issued Sept. 18, 1978)	Coal Mines: · Apply to all surface coal operations and surface effects of underground coal operations, whether coal estate is Federal, state, or privately owned. Anthracite Mines: · Reference Pennsylvania regulations as authority. Non-coal Mines: · Regulations do not apply.	Non-federal Land: · Case, line, or otherwise manage all underground openings to prevent pollution and mixing of surface or ground water, and ensure safety where openings create a hazard. · Cap, seal, or backfill each shaft, drift, adit, tunnel, exploratory hole, entryway or other opening to surface, as required by regulatory authority, in a manner consistent with MSHA regulations, unless otherwise approved. · Closure methods must be permanent to prevent access by people and animals and prevent flow of water. Federal Land: · Must meet same requirements as for non-federal land, but in addition specifies same provisions found in USGS requirements.	All Lands: · Regulations do not apply.

Units presented in these tables are as they appear in the original documents.

to underground mine closure.

CLOSURE TIME CONSTRAINTS	SUBSIDENCE CONTROL METHODS	EFFLUENT REQUIREMENTS	BONDING	MISC.
All Mines: · No specific mention. (1, 2)	All Mines: · No specific mention. (1, 2)	Coal Mines: · Federal EPA & OSM, as well as state, effluent limitations apply. Non-coal Mines: · Federal EPA and state effluent limitations apply.	All Mines: · No specific mention. (1, 2)	
Coal Mines (Non-federal Land): · In a timely manner. Coal Mines (Federal Land): · Commence without delay following cessation of mining operations. Non-coal Mines (All Lands): · Regulations do not apply.	Coal Mines (All Lands): · Plan and conduct activities to prevent subsidence from causing material damage to the surface, to extent technologically and economically feasible. · Leave adequate coal in place, backfill, or use other measures to support the surface, or mine in such a manner that provides for planned and controlled subsidence. · Operator must have and comply with an approved subsidence monitoring plan. · Require special provisions for particular buffer zones (public buildings, intermittent or perennial streams or impoundments with storage volume ≥ 20 acre-feet, and aquifers which serve as sole source	Coal Mines (All Lands): · Federal EPA and state effluent limitations, as well as the following OSM minimum limits, apply: Effluent Characteristics — Max. Allowable Iron (total) 7.0 mg/l Manganese^2 (total) 4.0 mg/l T.S.S.^{3} 70.0 mg/l pH^4 6.0-9.0 Effluent Characteristics Iron (total) 3.5* Manganese^2 (total) 2.0* T.S.S.^{3} 35.0* *Average of daily values for 30 consecutive discharge days.	Coal Mines (All Lands): · Amount of bond is determined by regulatory authority and based upon, but not limited to: estimated actual cost to regulatory authority if it had to perform reclamation, restoration and abatement work required; applicable performance standards; and provisions of the permit. · Period of bond liability continues for a sufficient period to ensure that requirements of reclamation plan and approved permit have been successfully met. Non-coal Mines (All Lands): · Regulations do not apply.	

TABLE 4. - Federal regulations related

FEDERAL REGULATORY AGENCY	TITLE OF REGULATIONS	JURISDICTIONAL AUTHORITY	CLOSURE METHODS	
			COAL	NON-COAL
Department of the Interior, Office of Surface Mining Reclamation and Enforcement (cont'd)	Proposed Rules for Permanent Regulatory Program (issued Sept. 18, 1978)			

Units presented in these tables are as they appear in the original documents.

to underground mine closure - (Cont'd.)

CLOSURE TIME CONSTRAINTS	SUBSIDENCE CONTROL METHODS	EFFLUENT REQUIREMENTS	BONDING	MISC.
	of water for municipal water systems); provisions include limiting percentage of coal extraction, adding support or backfill material, or prohibiting mining. Non-coal Mines (All Lands): · Regulations do not apply.	[1] Based on representative sampling. [2] The manganese limitation shall not apply to untreated discharges which are alkaline as defined by EPA (40 CFR 434). [3] In Arizona, Colorado, Montana, New Mexico, North Dakota, South Dakota, Utah, and Wyoming, total suspended solids limitations will be determined on a case by-case basis, but must not be greater than 45 mg/l (maximum allowable) and 30 mg/l (average of daily value for 30 consecutive discharge days), based on a representative sampling. [4] Where the application of neutralization and sedimentation treatment technology results in inability to comply with the manganese limitations set forth, the regulatory authority may allow the pH level in the discharge to exceed to a small extent the upper limit of 9.0 in order that the manganese limitations will be achieved. · If discharge does not meet effluent limitations when mine closes, treatment facilities must be maintained until discharge meets requirements without treatment or until discharge ceases. · Locate, design, construct, and utilize all underground mine openings so as to prevent or control gravity discharge. - Gravity discharges are permitted if they meet certain conditions, including effluent limitations.		

TABLE 4. - Federal regulations related

FEDERAL REGULATORY AGENCY	TITLE OF REGULATIONS	JURISDICTIONAL AUTHORITY	CLOSURE METHODS	
			COAL	NON-COAL
Department of the Interior, Office of Surface Mining Reclamation and Enforcement (cont'd)	Proposed Rules for Permanent Regulatory Program (issued Sept. 18, 1978)			
Department of the Interior, Geological Survey	30 CFR Mineral Resources; Chapter II - Geological Survey; Part 211 - Coal Mining Operating Regulations (1); Part 231 - Operating Regulations for Exploration, Development, and Production (2)	All Mines: · Apply to operations under leases, licenses or permits issued for Federally owned minerals, regardless of surface ownership. (1, 2)	· Close all openings, including water discharge points, in accordance with sound engineering practices and according to approved plan; methods of abandonment may include backfilling, regrading, revegetation, cementing, and capped casing, or combinations of these, or other methods. (1)	· Close all abandoned openings, including water discharge points, to the satisfaction of mining supervisor. (2)
Department of the Interior, Bureau of Land Management	43 CFR Public Lands: Interior; Chapter II - Bureau of Land Management; Part 3040 - Environment and Safety; Subpart 3041 - Surface Management and Protection	Coal Mines: · Apply to operations under leases and licenses issued for Federally owned coal by the BLM, regardless of surface ownership; specifically authorizes USGS as responsible for management of mineral resources, including authorizing the abandonment of operations, in consultation with BLM or other appropriate surface mining agency and the surface owner (if not the United States). Non-coal Mines: · Not under the authority of Subpart 3041 - Surface Management and Protection.	· Close all openings, including water discharge points, in accordance with sound engineering practices and according to approved plan; methods of abandonment may include backfilling, regrading, revegetation, cementing, and capped casing, or combinations of these, or other methods.	· Regulations do not apply.

Units presented in these tables are as they appear in the original documents.

to underground mine closure - (Cont'd.)

CLOSURE TIME CONSTRAINTS	SUBSIDENCE CONTROL METHODS	EFFLUENT REQUIREMENTS	BONDING	MISC.
		- No gravity discharges permitted for drift mines located in acid- or iron-producing coal seams. Non-coal mines (All lands): · Federal EPA and state effluent limitations apply.		
All Mines: · Commence without delay following cessation of mining operation. (1, 2)	Coal Mines: · Adopt measures consistent with feasible known technology to prevent or, where mining method used requires planned subsidence, control subsidence. (1) · May require a subsidence monitoring system. (1) Non-coal Mines: · No specific mention. (2)	Coal Mines: · Federal EPA & OSM, as well as state, effluent limitations apply. Non-coal Mines: · Federal EPA and state effluent limitations apply.	Coal Mines: · Bonds, at all times, must be adequate to satisfy the estimated costs for completion of the remaining reclamation. (1) · Where operator has complied with terms of all leases, permits, or licenses, and with approved operating plan, the Regional Director shall recommend the period of bonded liability be terminated. (1) Non-coal Mines: · No specific mention. (2)	
Coal Mines: · Commence without delay following cessation of mining operations. Non-coal Mines: · Regulations do not apply.	Coal Mines: · Adopt measures consistent with feasible known technology to prevent or, where mining method used requires planned subsidence, control subsidence. Non-coal Mines: · Regulations do not apply.	Coal Mines: · Federal EPA & OSM, as well as state, effluent limitations apply. Non-coal Mines: · Federal EPA and state effluent limitations apply.	Coal Mines: · Amount of bond must be sufficient to ensure reclamation in accordance with reclamation standards. · Where operator has complied with terms of all leases, permits, or licenses, and with approved operating plan, the mining supervisor shall recommend the period of bonded liability be terminated. Non-coal Mines: · Regulations do not apply.	

TABLE 4. - Federal regulations related

FEDERAL REGULATORY AGENCY	TITLE OF REGULATIONS	JURISDICTIONAL AUTHORITY	CLOSURE METHODS	
			COAL	NON-COAL
Department of Agriculture, Forest Service	36 CFR; Chapter II - Forest Service; Part 252 - Minerals	All Mines: · Apply to operations within any unit of the National Forest System.	· No specific mention.	· No specific mention.
Department of the Interior, National Park Service	36 CFR Parks, Forests, and Public Property; Chapter I - National Park Service; Part 9 - Mining and Mining Claims	All Mines: · Apply to operations within any unit of the National Park System.	· No specific mention.	· No specific mention.
Department of the Interior, Bureau of Indian Affairs	25 CFR; Chapter I - Bureau of Indian Affairs; Subchapter P - Mining	All Mines: · Apply to operations on Indian lands; mining regulations are cross-referenced to USGS in that if specific provisions are lacking, USGS regulations are authority.	· No specific mention; USGS regulations apply.	· No specific mention; USGS regulations apply.

Units presented in these tables are as they appear in the original documents.

to underground mine closure - (Cont'd.)

CLOSURE TIME CONSTRAINTS	SUBSIDENCE CONTROL METHODS	EFFLUENT REQUIREMENTS	BONDING	MISC.
All Mines: · No specific mention.	All Mines: · No specific mention.	Coal Mines: · Federal EPA & OSM, as well as state, effluent limitations apply. Non-coal Mines: · Federal EPA and state effluent limitations apply.	All Mines: · When required by authorized officer, furnish a bond conditioned upon compliance with requirements for environmental protection. · In determining amount of bond, consideration is given to estimated cost of reclaiming the area of operations.	
All Mines: · No specific mention.	All Mines: · Provide for the prevention of surface subsidence (applies only to patented claims with surface use restrictions and unpatented claims).	Coal Mines: · Federal EPA & OSM, as well as state, effluent limitations apply. Non-coal Mines: · Federal EPA and state effluent limitations apply.	All Mines: · Require performance bond in amount equal to estimated cost of reclamation. · Bond is released when all required reclamation is completed.	
All Mines: · No specific mention; USGS regulations apply.	All Mines: · No specific mention; USGS regulations apply.	Coal Mines: · Federal EPA & OSM, as well as state, effluent limitations apply. Non-coal Mines: · Federal EPA and state effluent limitations apply.	All Mines: · Require bonding in amount sufficient to satisfy reclamation requirements.	

State Level Regulations

State regulations relative to mine closure are summarized in Table 5. As the column on the right page of this table indicates, the regulatory factors impacting mine closure, other than those closure requirements specifically cited, were determined to be closure time constraints, subsidence control requirements, effluent limitations, and bonding requirements. Closure time constraints and bonding requirements can both give clues as to how soon after closure a seal must be constructed, and the subsequent period of time during which the mine operator is responsible for the maintenance and effectiveness of that seal.

The effluent requirements presented in this table are those promulgated for mine discharges, but as mentioned previously, basin-by-basin water quality or stream standards can locally impose even more stringent limitations during and after mining by requiring that a specific level of water quality be maintained. The effluent requirements are referenced to those published sources which were reviewed. In addition, some effluent limitation values promulgated pursuant to publication of the reference documents cited were obtained through personal contacts with appropriate state water quality regulatory personnel.

The state regulation summary table also includes, when specified in the source regulations, references to metal and non-metal mines in addition to the coal/non-coal requirements presented. However, these metal/non-metal categories have been presented for comparison purposes only and do not necessarily mean that every non-coal, metal or non-metal mineral is regulated in its respective category. Particular minerals may or may not be regulated depending upon the individual state regulatory authority's definition of what commodities are included in the metal and nonmetal categories. The following notes apply to Table 5.

- In addition to requiring the control of effluent pollutants during active mining operations, many states require mine plans describing how a polluted mine discharge will be prevented or abated after completion of mining.
- Where the phrase "No State Regulations Apply" occurs, appropriate federal regulations, as described above, fill the void. Where "No Specific Mention" is found in the table, state regulatory agencies may exercise control through the permitting process. This is especially true of surface subsidence, which is generally not mentioned in state statutes, but which is expected to be dealt with thoroughly in the mine plan submitted in support of a mining permit application, which is given definite consideration by the permitting agency during its' review.
- Surface subsidence has reached a point in Illinois where that state recently enacted a mine subsidence Act and insurance statute, and an Act to study and regulate mine subsidence. A study will also be made of existing laws, rules, and regulations designed to prevent mine subsidence that can be enforced by governmental units.
- It was generally noted during the review of the regulations that states require notification and mapping when underground mining operations are terminated.
- Local government land-use controls and permit requirements are also applicable to mining operations.
- State regulations, like the Federal reguations, are undergoing constant updating and revision as technological advances make more stringent requirements economically feasible. Presently, the Arkansas regulations are being revised, and the State of Idaho is in the process of phasing out its own regulations entirely, in favor of adopting MSHA standards.

TABLE 5. - State regulations related

STATE	REGULATORY AGENCIES	TITLE OF REGULATIONS #	CLOSURE METHODS	
			COAL	NON-COAL
Alabama	Department of Industrial Relations (1, 2) Water Improvement Commission (3, 4)	Coal Mining Laws of the State of Alabama (1),1975 Mine Safety Rules of the State of Alabama (2),1962 Surface Mining Regulations of the Alabama Water Improvement Commission (3),1978 Alabama Waste Discharge Permit Policies and Procedures (4),1972	· Fence and guard abandoned underground workings or post warning signs. (2)	· Fence and guard abandoned underground workings or post warning signs. (2)
Alaska*				
Arizona	Office of the State Mine Inspector (1) Department of Health Services (2, 3)	Mining Code of the State of Arizona (1),1976 Water Quality Standards for Surface Waters (2),1976 Arizona Water Pollution Control Law (3),1975	· Not Applicable	· Securely cover, fence, or otherwise protect all abandoned shafts, prospect holes, or other excavations endangering life or safety and post warning signs. (1)
Arkansas	Office of the State Mine Inspector (1) Department of Pollution Control and Ecology (2, 3)	Mining Laws of the State of Arkansas (1),1962 Arkansas Water and Air Pollution Control Act (2),1975 Arkansas Water Quality Standards, Regulation No. 2, as amended (3),1975	· Not Applicable	· No state regulations apply.
California	Department of Industrial Relations, Division of Industrial Safety (1) State Water Resources Control Board (2, 3)	California Mine Safety Orders (1),1978 Regulations Concerning Waste Discharge Requirements, NPDES (2),1977 The Porter-Cologne Water Quality Control Act (3),1977	· Not Applicable	· Securely cover over, fence, or otherwise effectively guard every dangerous inactive surface excavation, including any tunnel, mine shaft, pit, or other abandoned excavation. (1)
Colorado	Department of Natural Resources, Division of Mines (1, 2) Department of Health (3) Water Quality Control Commission (4, 5)	Coal Mining Laws, State of Colorado (1),1973 Colorado Mining Laws with Safety and Health Rules and Regulations (2),1976 Water Pollution Control (3),1972	· The owner of coal mines having surface caves or shafts deep enough to endanger persons or animals must fence or fill such areas. (1)	· Erect substantial fencing or other safeguards of sufficient strength to keep persons or animals out and post trespass warning signs. (2)

*No state regulations apply.

#Dates in this column refer to most recent amendment, effective date, or published date of specific regulation.

to underground mine closure.

CLOSURE TIME CONSTRAINTS	SUBSIDENCE CONTROL METHODS	EFFLUENT REQUIREMENTS	BONDING	MISC.
All Mines: • No specific mention. (1, 2)	All Mines: • No specific mention. (1, 2)	Coal Mines: • Federal EPA & OSM effluent limitations apply. (3, 4) Non-coal Mines: • Federal EPA effluent limitations apply. (3, 4)	All Mines: • No specific mention. (1, 2)	
Coal Mines: • No state regulations apply. Non-coal Mines: • No specific mention. (1)	Coal Mines: • No state regulations apply. Non-coal Mines: • No specific mention. (1)	Coal Mines: • Federal EPA & OSM effluent limitations apply. (2, 3) Non-coal Mines: • Federal EPA effluent limitations apply. (2, 3)	Coal Mines: • No state regulations apply. Non-coal Mines: • No specific mention. (1)	
Coal Mines: • No specific mention. (1) Non-coal Mines: • No state regulations apply.	Coal Mines: • No specific mention. (1) Non-coal Mines: • No state regulations apply.	Coal Mines: • Federal EPA & OSM effluent limitations apply. (2, 3) Non-coal Mines: • Federal EPA effluent limitations apply. (2, 3)	Coal Mines: • No specific mention. (1) Non-coal Mines: • No state regulations apply.	
Coal Mines: • No state regulations apply. Non-coal Mines: • No specific mention. (1)	Coal Mines: • No state regulations apply. Non-coal Mines: • No specific mention. (1)	Coal Mines: • Federal EPA & OSM effluent limitations apply. (2, 3) Non-coal Mines: • Federal EPA effluent limitations apply. (2, 3)	Coal Mines: • No state regulations apply. Non-coal Mines: • No specific mention. (1)	
All Mines: • Upon abandonment. (1, 2)	All Mines: • No specific mention. (1, 2)	Coal Mines: • Federal EPA & OSM effluent limitations apply. (3, 4, 5) Non-coal Mines: • Federal EPA effluent limitations apply. (3, 4, 5)	Coal Mines: • No specific mention. (1) Non-coal Mines: • The Commissioner of Mines, for reasonable cause, may require posting of a performance bond for stabilization work. (2)	Non-coal Mines: • Keep fencing in good repair. (2)

Units presented in these tables are as they appear in the original documents.

TABLE 5. - State regulations related

STATE	REGULATORY AGENCIES	TITLE OF REGULATIONS #	CLOSURE METHODS	
			COAL	NON-COAL
Colorado (cont'd)		Colorado Regulations for the State Discharge Permit System (4) ,1978 Colorado Regulations for Effluent Limitations (5),1975		
Connecticut †				
Delaware †				
Florida†				
Georgia*				
Hawaii†				
Idaho	Department of Labor and Industrial Services (1) Department of Health and Welfare, Division of Environment (2)	Idaho Minimum Safety Standards and Practices for Mining and Mineral Industry (1),1976 Water Quality Standards and Wastewater Treatment Requirements (2) ,1973	· Not Applicable	· Effectively close or fence off all surface openings through which persons could fall or enter; post trespass warnings and appropriate danger notices upon or near all safeguards. (1)
Illinois	Department of Mines and Minerals (1, 2) Environmental Protection Agency (3, 4)	The Coal Mining Act, State of Illinois (1),1975 Illinois Laws and Regulations Governing the Operation of Metal Mines (2),1973 Illinois Environmental Protection Act (3),1978 Illinois Pollution Control Board Rules and Regulations (4),1972	· Fill shaft, slope or drift openings with earth or other material, or keep permanently enclosed and sealed. (1)	Metal: · Securely fence all mill holes, glory holes, or cavernous stopes opening to the surface, if within 300 ft. of highway or thoroughfare. (2) · Securely cover or fence all abandoned shafts. (2) · Securely fence all other abandoned excavations where side slopes are >40 degrees and depth is >10 feet. (2) Non-metal: · No state regulations apply.

*No state regulations apply.

† No underground mining.

#Dates in this column refer to most recent amendment, effective date, or published date of specific regulation.

to underground mine closure - (Cont'd.)

CLOSURE TIME CONSTRAINTS	SUBSIDENCE CONTROL METHODS	EFFLUENT REQUIREMENTS	BONDING	MISC.
All Mines: · Upon abandonment. (1)	All Mines: · No specific mention. (1)	Coal Mines: · Federal EPA & OSM effluent limitations apply. (2) Non-coal Mines: · Federal EPA effluent limitations apply. (2)	All Mines: · No specific mention. (1)	
Coal Mines: · At the discretion of the State Mine Inspector. (1) Metal Mines: · No specific mention. (2) Non-metal Mines: · No state regulations apply.	Coal and Metal Mines: · No specific mention. (1, 2) Non-metal Mines: · No state regulations apply.	All Mines: · Federal EPA (as well as OSM requirements for coal) and state limitations apply, whichever are the more stringent; following are state limitations*: Total acidity shall not exceed total alkalinity. Iron (total) - 7 mg/l Lead (total) - 1 mg/l **Nitrogen - 5 mg/l pH - 5.0 to 10.0 Zinc (total) - 5 mg/l Flouride (total) - 8 mg/l Total Suspended Solids - 50 mg/l to be met only when treatment facilities are otherwise provided to meet the above contaminant levels; during storm	Coal and Metal Mines: · No specific mention. (1, 2) Non-metal Mines: · No state regulations apply.	Metal Mines: · Maintain all fencing and coverings. (2)

Units presented in these tables are as they appear in the original documents.

TABLE 5. - State regulations related

STATE	REGULATORY AGENCIES	TITLE OF REGULATIONS#	CLOSURE METHODS	
			COAL	NON-COAL
Illinois (cont'd)				
Indiana	Bureau of Mines and Mining (1) State Board of Health, Stream Pollution Control Board (2)	Coal Mining Laws of Indiana (1),1975 Water Quality Standards for all Waters within the State of Indiana (2) ,1977	· Fill all entrances to abandoned mines.(1) – Fill vertical openings from bottom to top. – Fill and seal all other openings in manner prescribed by regulatory authority. · Effectively protect all unused, abandoned, and isolated surface openings against unauthorized entry. (1)	· No state regulations apply.
Iowa*				
Kansas	Kansas Corporation Commission (1) Department of Health and Environment, Division of Environment (2) Department of Health and Environment, Water Quality Management Section (3) State Board of Health (4)	Kansas Statutes Pertaining to Mines and Mining (1),1975 Kansas Statutes Pertaining to Water Pollution Control (2),1974 Kansas Surface Water Quality Standards (3) ,1978 Kansas Statutes, State Board of Health Regulations (4),1974	· Not Applicable	· Properly fence off entrance of every abandoned shaft or slope. (1)
Kentucky	Department of Mines and Minerals (1) Department for Natural Resources and Environmental Protection (2, 3, 4)	Laws Governing the Mining of Coal and Clay, Kentucky Revised Statutes (1),1976 Kentucky Stream Discharge Regulations (2),1975	· No specific mention. (1)	Clay Mines: · No specific mention. (1) Other Non-coal Mines: · No state regulations apply.

*No state regulations apply.

#Dates in this column refer to most recent amendment, effective date, or published date of specific regulation.

to underground mine closure - (Cont'd.)

CLOSURE TIME CONSTRAINTS	SUBSIDENCE CONTROL METHODS	EFFLUENT REQUIREMENTS	BONDING	MISC.
		episodes up to 150 mg/l may be allowed. (3, 4) *These apply as instantaneous maximums where no waste treatment in addition to impoundment is provided and as daily averages where waste treatment is provided. **Applicable only when operator utilizes ammonia in wastewater treatment.		
Coal Mines: · Immediately following abandonment. (1) **Non-coal Mines:** · No state regulations apply.	**Coal Mines:** · No specific mention. (1) **Non-coal Mines:** · No state regulations apply.	**Coal Mines:** · Federal EPA & OSM effluent limitations apply. (2) **Non-coal Mines:** · Federal EPA effluent limitations apply. (2)	**Coal Mines:** · No specific mention. (1) **Non-coal Mines:** · No state regulations apply.	**Coal Mines:** · Maintain filled condition of vertical openings. (1)
All Mines: · No specific mention. (1)	**All Mines:** · No specific mention. (1)	**Coal Mines:** · Federal EPA & OSM effluent limitations apply. (2, 3, 4) **Non-coal Mines:** · Federal EPA effluent limitations apply. (2, 3, 4)	**All Mines:** · No specific mention. (1)	
Coal and Clay Mines: · No specific mention. (1) **Other Non coal Mines:** · No state regulations apply.	**Coal and Clay Mines:** · No specific mention. (1) **Other Non coal Mines:** · No state regulations apply.	**Coal Mines:** · Federal EPA & OSM effluent limitations apply. (2, 3, 4) **Non coal Mines:** · Federal EPA effluent limitations apply. (2, 3, 4)	**Coal and Clay Mines:** · No specific mention. (1) **Other Non coal Mines:** · No state regulations apply.	

Units presented in these tables are as they appear in the original documents.

TABLE 5. - State regulations related

STATE	REGULATORY AGENCIES	TITLE OF REGULATIONS #	CLOSURE METHODS	
			COAL	NON-COAL
Kentucky (cont'd)		Water Quality Standards for the Commonwealth of Kentucky (3) ,1974 Kentucky Environmental Protection Law (4) ,1974		
Louisiana*				
Maine†				
Maryland	Department of Natural Resources (1) Department of Health (2) Water Resources Administration (3, 4)	Maryland State Department of Natural Resources Rules and Regulations (1),1977 Maryland Water Pollution Control Laws (2) ,1970 Maryland Water Resources Law (3),1974 Maryland Effluent Limitations (4),1974	· Seal all boreholes at the surface to prevent influx of water and to eliminate health and safety hazards. (1) - Seal at mined coal seam level to prevent influx of water and to protect integrity of seal against roof falls, subsidence, hydrostatic pressure, and other destructive forces. · Seal drift or slope entries. (1) - Use impervious incombustible material. - Locate and construct seals to prevent transfer of water through entries unless otherwise approved. - Where hydrostatic pressure is anticipated, anchor seals ≥2 feet into sides, roof, and floor of entry. · Cap or backfill shaft openings. (1) - Backfill with incombustible material free of debris and top with impervious layer ≥4 feet thick shaped to prevent water impoundment; must allow for settling of fill.	· No state regulations apply.

*No state regulations apply.

† No underground mining.

#Dates in this column refer to most recent amendment, effective date, or published date of specific regulation.

to underground mine closure - (Cont'd.)

CLOSURE TIME CONSTRAINTS	SUBSIDENCE CONTROL METHODS	EFFLUENT REQUIREMENTS	BONDING	MISC.
Coal Mines: · No specific mention. (1) Non-coal Mines: · No state regulations apply.	Coal Mines: · Provide support for structures not controlled by operator. (1) - In areas with a surface slope ≤ 5%, determine protected area by projecting a 25° angle down and outward from perimeter of structure; in areas with a surface slope > 5%, an area equal in width to the surface slope (in percent) times the depth to the coal seam (in feet), must be added to downslope side of projected support area. - ≥ 50% of mineral mined must remain as evenly distributed pillars in the support area. - Minimum length and width of each pillar must be 40 feet. Non-coal Mines: · No state regulations apply.	Coal Mines: · Federal EPA, as well as OSM requirements, and state limitations apply, whichever are the more stringent; following are state limitations: pH-Instantaneous max. 6.0 to 9.0 Turbidity - Instanteous max. 100 JTU Total Suspended Solids-Instantaneous max. 45 mg/l Monthly avg. 30 mg/l Total Iron - Instantaneous max. 7.0 mg/l Monthly avg. 3.5 mg/l Alkalinity* - Instantaneous min. 20 mg/l (2, 3, 4) * Alkalinity requirement applies only where treating to remove iron. Non-coal Mines: · Federal EPA effluent regulations apply. (2, 3, 4)	Coal Mines: · Bonding is required equal to the cost of reclamation. (1) · Liability extends under the bond for a period of 5 years after abandonment unless previously released by the regulatory authority. (1) Non-coal Mines: · No state regulations apply.	

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TABLE 5. - State regulations related

STATE	REGULATORY AGENCIES	TITLE OF REGULATIONS #	CLOSURE METHODS	
			COAL	NON-COAL
Maryland (cont'd)			May use caps with ≥six inch thick reinforced concrete or equivalent, if mine is to reopen within 5 years.	
Massachusetts†				
Michigan*				
Minnesota*				
Mississippi†				
Missouri	Department of Labor and Industrial Relations, Division of Mine Inspection (1) Department of Natural Resources, Clean Water Commission (2)	Mine Inspection Regulations, Missouri Labor Laws (1),1976 Missouri Water Pollution Control Regulations (2) ,1978	· Not Applicable	· Seal or fence surface openings to afford permanent protection to all persons and animals. (1)
Montana	Department of Labor and Industry, Workmen's Compensation Division, Bureau of Safety and Health (1,2) Department of Health and Environmental Sciences (3)	Montana Administrative Code, Chapter 18A II - Mines Section (1),1976 Montana Safety and Health Standards for Metal and Nonmetallic Mining and Related Industries (2),1972 Montana Pollutant Discharge Elimination System Regulations (3) ,1974	· Federal MSHA coal regulations are specifically referenced to be Montana's Safety and Health Rules and Regulations for Coal Mines. (1)	· Effectively close or fence off all surface openings through which persons could fall or enter; post trespass warnings and appropriate danger notices upon or near all such safeguards. (2)
Nebraska*				
Nevada*				
New Hampshire†				
New Jersey	Department of Labor and Industry (1) Department of Environmental Protection, Division of Water Resources (2, 3)	State of New Jersey Mine Safety Act (1) ,1973 New Jersey Water Pollution Control Regulations (2),1977 New Jersey Surface Water Quality Standards (3),1974	· Not Applicable	· Place guardrails, fences, effective and secure capping, or other protective measures which regulatory authority judges necessary to prevent injury to persons or damage to property, and post warning signs. (1)

*No state regulations apply.

†No underground mining.

#Dates in this column refer to most recent amendment, effective date, or published date of specific regulation.

to underground mine closure - (Cont'd.)

CLOSURE TIME CONSTRAINTS	SUBSIDENCE CONTROL METHODS	EFFLUENT REQUIREMENTS	BONDING	MISC.
All Mines: · Upon abandonment. (1)	All Mines: · Backfilling permitted during mining to provide additional ground support in mined-out areas with landowner's consent. (2)	Coal Mines: · Federal EPA & OSM effluent limitations apply. (2) Non-coal Mines: · Federal EPA effluent limitations apply. (2)	All Mines: · No specific mention. (1)	
Coal Mines: · No specific mention. (1) Non-coal Mines: · Upon abandonment. (2)	All Mines: · No specific mention. (1, 2)	Coal Mines: · Federal EPA & OSM effluent limitations apply. (3) Non-coal Mines: · Federal EPA effluent limitations apply. (3)	All Mines: . No specific mention. (1, 2)	
All Mines: . At the discretion of regulatory authority. (1)	All Mines: . No specific mention. (1)	Coal Mines: . Federal EPA & OSM effluent limitations apply. (2, 3) Non-coal Mines: . Federal EPA effluent limitations apply. (2, 3)	All Mines: . No specific mention. (1)	

Units presented in these tables are as they appear in the original documents.

TABLE 5. - State regulations related

STATE	REGULATORY AGENCIES	TITLE OF REGULATIONS#	CLOSURE METHODS	
			COAL	NON-COAL
New Mexico	Office of the State Mine Inspector (1) Water Quality Control Commission (2, 3)	New Mexico Mine Safety Code for All Mines (1),1975 Water Quality Control Commission Regulations (2),1977 New Mexico Water Quality Act (3),1973	· Not Applicable	· Effectively close or fence off all surface openings through which persons could fall or enter; post trespass warnings and appropriate danger notices upon or near all such safeguards. (1)
New York	Department of Labor, Board of Standards and Appeals (1) Department of Environmental Conservation (2, 3)	Industrial Code Rule 31-Underground Mining Operations (1),1970 New York Regulations on State Pollutant Discharge Elimination System (2),1976 New York Environmental Conservation Law, Article 17 - Water Pollution Control (3),1977	· Not Applicable	· Securely fence or completely close all abandoned excavations. (1)
North Carolina*				
North Dakota†				
Ohio	Department of Industrial Relations, Division of Mines. (1) Environmental Protection Agency (2, 3, 4)	Mining Laws of Ohio (1),1977 Ohio Water Pollution Control Act (2),1976 Ohio NPDES Permit Regulations (3),1973 Ohio Water Quality Standards (4),1977	· Effectively close or fence all openings to abandoned mines. (1) - Completely fill vertical shafts with earth or other noncombustible material, or cover top of shaft with substantial reinforced concrete slab which has been approved by regulatory authority. - Close other openings with earth or masonry in manner prescribed by regulatory authority to prevent unauthorized entry.	· Effectively close or fence all openings to abandoned mines. (1) - Completely fill vertical shafts with earth or other noncombustible material, or cover top of shaft with substantial reinforced concrete slab which has been approved by regulatory authority. - Close other openings with earth or masonry in manner prescribed by regulatory authority to prevent unauthorized entry.

*No state regulations apply.

† No underground mining.

#Dates in this column refer to most recent amendment, effective date, or published date of specific regulation.

to underground mine closure - (Cont'd.)

CLOSURE TIME CONSTRAINTS	SUBSIDENCE CONTROL METHODS	EFFLUENT REQUIREMENTS	BONDING	MISC.
All Mines: · Upon abandonment. (1)	All Mines: · No specific mention. (1)	Coal Mines: · Federal EPA & OSM effluent limitations apply. (2, 3) Non-coal Mines: · Federal EPA effluent limitations apply. (2, 3)	All Mines: · No specific mention. (1)	
All Mines: · No specific mention. (1)	All Mines: . No specific mention. (1)	Coal Mines: . Federal EPA & OSM effluent limitations apply. (2, 3) Non-coal Mines: . Federal EPA effluent limitations apply. (2, 3)	All Mines: . No specific mention. (1)	
All Mines: . Within 90 days after abandonment. (1)	All Mines: . No specific mention. (1)	Coal Mines: . Federal EPA & OSM effluent limitations apply. (2, 3, 4) Non-coal Mines: . Federal EPA effluent limitations apply. (2, 3, 4)	All Mines: . No specific mention. (1)	

Units presented in these tables are as they appear in the original documents.

TABLE 5. - State regulations related

STATE	REGULATORY AGENCIES	TITLE OF REGULATIONS #	CLOSURE METHODS	
			COAL	NON-COAL
Oklahoma	Office of the Chief Mine Inspector (1) Water Resources Board (2) State Department of Health (3)	Mining Laws of the State of Oklahoma (1), 1973 Oklahoma Pollution Remedies Laws (2), 1972 Oklahoma Water Pollution Control Laws (3), 1974	· Not Applicable	Metal Mines: . Cover suitably, surround with protective fencing, or plug and fill all abandoned vertical shafts, as approved by regulatory authority. (1) Non-metal Mines: . Fill with earth or other incombustible material, or keep permanently enclosed and sealed, all shaft, slope, or drift openings into any abandoned mine. (1)
Oregon	Workmen's Compensation Department (1) Department of Environmental Quality (2, 3)	Oregon Safety Code for Mining, Tunneling and Quarrying (1), 1962 Regulations Relating to Water Quality Control in Oregon (2), 1977 Oregon Water Pollution Control Laws (3), 1977	· Not Applicable	· No specific mention. (1)
Pennsylvania	Department of Environmental Resources (1, 2, 4 - 11) Department of Labor and Industry (3)	Pennsylvania Bituminous Coal Mine Act (1), 1970 Pennsylvania Anthracite Coal Mine Act (2), 1965 Regulations for Mines Other than Coal Mines (3), 1964 The Clean Streams Law of Pennsylvania (4), 1976 Bituminous Mine Subsidence and Land Conservation Act of 1966 (5), 1966 Purdon's Pennsylvania Statutes, Title 52-Mines and Mining (6), 1961 Regulating Mining - Second Class Counties Act (7), 1937 State Mining Commissions Act (8), 1945 Pennsylvania Mine Drainage Permits Regulations (9), 1978	Bituminous: . Fill all abandoned shafts for entire depth, using incombustible fill from bottom of coal seam to a height of 50 feet. (1) . Fill every abandoned slope, drift, or tunnel with incombustible material for a distance of 25 feet. (1) . Effectively plug or seal abandoned driftholes and boreholes. (1) Anthracite: . Fill all abandoned shafts for entire depth. (2) . Fill every abandoned slope, drift, or tunnel with incombustible material for a distance of 25 feet. (2)	. Properly fence around or across entrance to every abandoned slope, shaft, air hole, drift, or other surface opening. (3) - Fences must be ≥ 4 feet high with warning signs posted.

#Dates in this column refer to most recent amendment, effective date, or published date of specific regulation.

to underground mine closure - (Cont'd.)

CLOSURE TIME CONSTRAINTS	SUBSIDENCE CONTROL METHODS	EFFLUENT REQUIREMENTS	BONDING	MISC.
Coal Mines: . At the discretion of the Chief Mine Inspector. (1) Metal Mines: . No specific mention. (1) Non-metal Mines . At the discretion of the Chief Mine Inspector. (1)	All Mines: . No specific mention. (1)	Coal Mines: . Federal EPA & OSM effluent limitations apply. (2, 3) Non-coal Mines: . Federal EPA effluent limitations apply. (2, 3)	All Mines: . No specific mention. (1)	
All Mines: . No specific mention. (1)	All Mines: . No specific mention. (1)	Coal Mines: . Federal EPA & OSM effluent limitations apply. (2, 3) Non-coal Mines: . Federal EPA effluent limitations apply. (2, 3)	All Mines: . No specific mention. (1)	
All Mines: . No specific mention. (1,2,3,4)	Bituminous Coal Mines: . In areas with a surface slope < 5%, determine protected area by projecting a 15° angle down and outward from offset lines drawn 15 feet from the structure to be protected; in areas with a surface slope ≥ 5%, an area equal in width to the surface slope (in percent) times the depth to the coal seam (in feet) must be added to downslope side of projected support area. (5) - ≥ 50% of mineral mined must remain as evenly distributed pillars in the support area. - Minimum pillar dimensions specified by	Coal Mines: . Federal EPA & OSM effluent limitations apply, except for additional state limitation that no discharge may be acid. (4,9,10,11) Non-coal Mines: . Federal EPA effluent limitations apply. (4, 9, 10, 11)	All Mines: . Department may require posting of bond to insure compliance with all applicable regulations and conditions of the permit, including provisions insuring there will be no polluting discharge after operations have ceased. (4) - Amount of bond is established by Department. - Liability continues until Department determines there is no further significant risk of a pollutional discharge. Bituminous Coal Mines: . Where operator does not possess adequate financial	All Mines: . Landowner (which includes any person holding title to or having a proprietary interest in either surface or subsurface rights) can be held responsible to correct any condition which results in pollution or a danger of pollution, including maintaining a seal; this applies only after bond is released. (4)

Units presented in these tables are as they appear in the original documents.

TABLE 5. - State regulations related

STATE	REGULATORY AGENCIES	TITLE OF REGULATIONS #	CLOSURE METHODS	
			COAL	NON-COAL
Pennsylvania (cont'd)		Pennsylvania NPDES Regulations (10), 1973 Pennsylvania Industrial Wastes Regulations (11), 1978	. Effectively plug or seal abandoned driftholes or boreholes with concrete. (2)	

#Dates in this column refer to most recent amendment, effective date, or published date of specific regulation.

to underground mine closure - (Cont'd.)

CLOSURE TIME CONSTRAINTS	SUBSIDENCE CONTROL METHODS	EFFLUENT REQUIREMENTS	BONDING	MISC.
	regulatory authority. . If operator does not possess adequate financial responsibility or has not filed a bond or other security, greater safety factors must be provided. (5) - Coal within an area determined by projecting perpendicular lines downward from offset lines drawn 125 feet from structure must remain in the virgin state. - Within an area determined by projecting a 25° angle down and outward from the 125 foot offset lines, ≥ 50% of coal must remain as evenly distributed pillars. - Minimum pillar dimensions specified by regulatory authority. Coal Mines: . It is unlawful to mine coal so as to cause subsidence of: public buildings, public passageways, any facility used in public service, any human dwelling or establishment where human labor is employed, or any cemetery. (5,6,7) . For state acquired land, the State Mining Commission determines: the amount of coal, if any, to be left in place to furnish vertical and		responsibility or has had permit revoked, a bond covering possible subsidence damage may be required. (5) - Amount is determined by regulatory authority. - Liability continues during mining and for a period of 10 years thereafter.	

Units presented in these tables are as they appear in the original documents.

TABLE 5. - State regulations related

STATE	REGULATORY AGENCIES	TITLE OF REGULATIONS#	CLOSURE METHODS	
			COAL	NON-COAL
Pennsylvania (cont'd)				
Rhode Island †				
South Carolina †				
South Dakota *				
Tennessee	Department of Labor, Division of Mines (1) Department of Public Health, Division of Water Quality Control (2, 3, 4)	Laws and Regulations Governing Mines and Mining in Tennessee (1) ,1976 Water Quality Control Act (2),1977 Tennessee Water Quality Control Board General Regulations(3) ,1977 Tennessee Effluent Limitations and Standards (4),1977	. Effectively protect all unused, abandoned, and isolated surface openings against unauthorized entrance. (1)	. No specific mention. (1)
Texas *				
Utah	Industrial Commission of Utah (1, 2) Division of Health (3, 4)	General Safety Orders, Utah Coal Mines (1) ,1976 State of Utah Metal and Non-metal Mines Health and Safety Standards (2),1978 Utah Water Pollution Control Act (3),1973 Utah Wastewater Disposal Regulations (4) ,1978	. Adequately close, cover, or fence off abandoned openings to shafts, slopes, and drifts, subject to approval of State Mine Inspector. (1)	. Effectively close or fence off all surface openings through which persons could fall or enter; post trespass warnings and appropriate danger notices upon or near all such safeguards. (2)
Vermont*				
Virginia	Department of Labor and Industry, Division of Mines (1) State Water Control Board (2)	Mining Laws of Virginia (1),1978 Virginia Discharge Permit Regulations(2) ,1975	. Effectively protect all unused, abandoned, and isolated surface openings against unauthorized entry. (1)	. Effectively protect all unused, abandoned, and isolated surface openings against unauthorized entry. (1)

* No state regulations apply.

† No underground mining.

#Dates in this column refer to most recent amendment, effective date, or published date of specific regulation.

to underground mine closure - (Cont'd.)

CLOSURE TIME CONSTRAINTS	SUBSIDENCE CONTROL METHODS	EFFLUENT REQUIREMENTS	BONDING	MISC.
	lateral support; the material, if any, to be substituted for the coal; and the method and manner of placing the substitute material. (8) Non-coal Mines: . No specific mention. (3)			
All Mines: . No specific mention. (1)	All Mines: . No specific mention. (1)	Coal Mines: . Federal EPA & OSM effluent limitations apply. (2,3,4) Non-coal Mines: . Federal EPA effluent limitations apply. (2,3,4)	All Mines: . No specific mention. (1)	
Coal Mines: . No specific mention. (1) Non-coal Mines: . Upon abandonment. (2)	All Mines: . No specific mention. (1)	All Mines: . Federal EPA (as well as OSM requirements for coal) and state limitations apply, whichever are the more stringent; following are state limitations: pH - 6.5 to 9 S.S. (max. 30 day avg.)-25 mg/l S.S. (max. 7 day avg.)-35 mg/l (3,4)	All Mines: . No specific mention. (1,2)	
All Mines: . No specific mention. (1)	All Mines: . No specific mention. (1)	Coal Mines: . Federal EPA & OSM effluent limitations apply. (2) Non-coal Mines: . Federal EPA effluent limitations apply. (2)	All Mines: . No specific mention. (1)	

Units presented in these tables are as they appear in the original documents.

TABLE 5. - State regulations related

STATE	REGULATORY AGENCIES	TITLE OF REGULATIONS#	CLOSURE METHODS	
			COAL	NON-COAL
Washington	Department of Labor and Industries (1,2) Department of Ecology (3, 4)	Coal Mining Laws of Washington (1),1966 Washington Safety Standards-Metal and Nonmetallic Mines(2) ,1972 Washington State Water Quality Standards(3) ,1977 Washington NPDES Permit Program Regulations (4)	. Fence or fill every abandoned slope, shaft, airhole or drift in such a manner as to afford proper and continuous protection to all persons and stock endangered thereby. (1)	. Effectively close or fence off all surface openings through which persons could fall or enter; post trespass warnings and appropriate danger notices at or near each opening. (2)
West Virginia	Department of Mines (1,2) Department of Natural Resources, Division of Water Resources (3,4)	Mining Laws of West Virginia (1),1977 Department of Mines Bond Application (2) Water Pollution Control Act (3),1976 West Virginia Water Quality Regulations (4) ,1978	. Properly seal all openings of abandoned mines. (1) - Cap or fill shaft openings: filling to be for entire depth; capping to be 6 inch thick concrete cap with vent pipe (≥ 2 inches in diameter) extending ≥15 feet above surface of shaft or other approved equivalent.	. Properly seal all openings of abandoned mines. (1) - Cap or fill shaft openings: filling to be for entire depth; capping to be 6 inch thick concrete cap with vent pipe (≥ 2 inches in diameter) extending ≥ 15 feet above surface of shaft or other approved equivalent.
Wisconsin	Department of Industry, Labor and Human Relations (1,2) Department of Natural Resources, Division of Environmental Protection (3,4)	Wisconsin Administrative Code, Chapter 3 - Mines, Pits, and Quarries (1),1978 West's Wisconsin Statutes, Annotated, Chapter 167- Safeguards of Persons and Property (2),1969 Wisconsin Water Pollution Control Laws (3),1977 Wisconsin Effluent Limitations and Standards for Pollutant Discharge Elimination System (4),1977	· Not Applicable	. Effectively close or fence off all surface openings through which persons could fall or enter; post trespass warnings and appropriate danger notices on or near all such safeguards. (1) . Fill to grade, enclose with fence, or cap any abandoned mine shaft. (1,2) - Erect fencing made of strong woven wire ≥ 46 inches wide, installed with no crawl space and with one barbwire above; strands of woven wire must be ≥ No. 12 wire and cross wires ≥ No. 16 wire with strands ≤ 12 inches

#Dates in this column refer to most recent amendment, effective date, or published date of specific regulation.

to underground mine closure - (Cont'd.)

CLOSURE TIME CONSTRAINTS	SUBSIDENCE CONTROL METHODS	EFFLUENT REQUIREMENTS	BONDING	MISC.
Coal Mines: . No specific mention. (1) Non-coal Mines: . Upon abandonment. (2)	All Mines: . No specific mention. (1,2)	Coal Mines: . Federal EPA & OSM effluent limitations apply. (3,4) Non-coal Mines . Federal EPA effluent limitations apply. (3,4)	All Mines: . No specific mention. (1,2)	
All Mines: . Within 90 days after abandonment. (1)	All Mines . No specific mention. (1)	All Mines: . Federal EPA (as well as OSM requirments for coal) and state limitations apply, whichever are the more stringent; following is a more stringent state limitation: pH -6.0 to 8.5 (3, 4)	All Mines: . Reclamation bond of $5,000 per acre is required for removal of unused surface structures, sealing of abandoned mine openings, and reclamation of any land disturbed. (1) . Bonding obligation remains in full force and effect until operator has faithfully fulfilled all applicable regulations. (2)	
All Mines: . Upon abandonment. (1,2)	All Mines: . No specific mention (1,2)	Coal Mines: . Federal EPA & OSM effluent limitations apply. (3,4) Non-coal Mines: . Federal EPA effluent limitations apply. (3,4)	All Mines; . No specific mention. (1,2)	All Mines: . Operator is responsible for maintenance of fencing. (2)

Units presented in these tables are as they appear in the original documents.

TABLE 5. - State regulations related

STATE	REGULATORY AGENCIES	TITLE OF REGULATIONS #	CLOSURE METHODS	
			COAL	NON-COAL
Wisconsin (cont'd)			· Not Applicable	apart and meshes ≤8 inches square; stretch all wires tightly and fasten securely to sufficient posts set firmly ≤ 8 feet apart. - Cap with reinforced concrete slab ≥6 inches thick; or boulder ≥3 times diameter of top of shaft; or with a tapered concrete plug.
Wyoming	Office of the State Inspector of Mines (1,2) Department of Environmental Quality (3,4)	Coal Mining Laws of the State of Wyoming(1),1973 Wyoming Non-coal Mining Laws (2),1971 Wyoming Water Quality Rules and Regulations (3),1974 Wyoming Water Quality Standards (4),1974	. Effectively close or fence off all surface openings through which persons or animals could fall or enter. (1)	. Effectively close or fence off all surface openings through which persons or animals could fall or enter.(2)

#Dates in this column refer to most recent amendment, effective date, or published date of specific regulation.

to underground mine closure - (Cont'd.)

CLOSURE TIME CONSTRAINTS	SUBSIDENCE CONTROL METHODS	EFFLUENT REQUIREMENTS	BONDING	MISC.
All Mines: . Upon abandonment or indefinite closing down of mine. (1,2)	All Mines: . No specific mention. (1,2)	Coal Mines: . Federal EPA, as well as OSM requirements, and state limitations apply, whichever are the more stringent; following are state limitations: pH - Instantaneous max. 6.0 to 9.0 Oil Grease - Instantaneous max. 10mg/l TSS- Daily avg. 20mg/l Daily max. 30mg/l Instantaneous max. 45mg/l Fe- Daily avg. 3.0mg/l Daily max. 6.0mg/l Instantaneous max. 9.0mg/l (3,4) Non-coal Mines: . Federal EPA effluent limitations apply. (3,4)	Coal Mines: . No specific mention. (1) Non-coal Mines: . Where a mining right exists separate from surface ownership, surface owner may demand security for possible subsidence by requiring operator to post bond and may enjoin mining until such security is given. (2)	

Units presented in these tables are as they appear in the original documents.

POST-CLOSURE DAMAGE LIABILITIES

Contacts with state and federal officials concerning underground mining laws, revealed no explicit post-closure damage liability statutes. Therefore, the information provided in this section was obtained through further contacts made with state and federal legal counselors attached to either mining or environmental agencies or Attorneys' General's offices. The following discussion summarizes the information obtained from these legal counselors supplemented by project research. It basically defines the various general avenues of approach which may be utilized in determining post-closure damage liability issues. Due to the considerable complexity of these issues and the numerous variables involved, a minimum of specific information was offered by these legal personnel; their basic approach to each specific lawsuit is to conduct case law research, a task that lies well beyond the scope of this study. The following general summarization of post-closure damage liability issues is presented for limited informational purposes only; it is not offered as legal advice or as a legal analysis of the issues, nor is it intended to be totally comprehensive in nature.

As indicated, the objective of this discussion is to define the common law doctrines and types of statutes which are relevant in determining two critical issues: 1) who is liable; and 2) under what circumstances or conditions is liability imposed. In the course of discussing these issues, other topics such as the following will be included:

1) Statute of limitations
2) Enforcement proceedings (regulatory hearing or court suits, etc.)

4) Types of suits (civil, criminal)
5) Penalties and limits set
6) Statutes or common law doctrines invoked

Historically, common law courts have applied the ordinary rules of tort law and contract law to the operation of mines. Therefore, actions against owners or operators of mines for damages resulting from the operation of their mines are usually governed by the rules which apply in civil actions. As a consequence, a mine operator falls under the general rule requiring a person to operate a business without causing damage to, or destruction of, his neighbor's or public property. However, it is also a general rule that the extracting of minerals from one's own property is a right incident to that ownership and therefore, a mine operator is not liable to others for incidental annoyances or injuries resulting from the natural and reasonable course of mining so long as the business is conducted in the ordinary way and with the usual and customary precautions. Thus, while the owner of a mine who operates it in a natural and reasonable way is not ordinarily liable to an adjoining mine owner for injuries from percolating waters, for example, he is, however, strictly liable for a breach in an absolute duty, such as subjacent support.

Presented below is a clarification of this very complex issue of mine operator liability. Presented first is a discussion of the general common law legal theories which apply. Thereafter, specific statutory responses (including citations by those legal counselors previously mentioned) which directly or indirectly might be used in determining post-closure damage liability are identified.

Common Law Theories

The legal theories which are most often applied in post-closure damage liability cases can be broken down into five basic categories:

1) Negligence
2) Negligence per se (breach of statutory or regulatory duty)
3) Nuisance
4) Subjacent of lateral support with strict liability
5) Breach of contractual duty and general leasehold principles

Three general categories or types of post-closure damages which present the possibility of legal liability are: 1) acid mine drainage damage; 2) subsidence related damage; and 3) bodily injury. To summarize the subsequent discussion and to aid in a better understanding of the legal issues discussed, the following is a breakdown of the legal theories generally involved in the three types of post-closure damage liability, in the respective order of frequency with which they are cited.

Acid Mine Drainage:

1) Nuisance theory and negligence per se (breach of statutory or regulatory duty, such as public nuisance statutes or water quality regulations)
2) Negligence
3) Breach of contractual duty and general leasehold principles can apply when legal suit is brought on by surface owner against mine operator discharging on surface owner's land.

Subsidence Damage:

1) Subjacent or lateral support and negligence per se (breach of statutory or regulatory duty dealing with subsidence control measures.
2) Negligence
3) Breach of contractual duty and general leasehold principles (as can apply when mine operator fails to faithfully perform all subsidence control duties dictated by lease with surface owner).

Bodily Injury:

1) Negligence and negligence per se (breach of statutory or regulatory duty dealing with faithfully performing specified mine closure procedures
2) Nuisance
3) Breach of contractual duty and general leasehold principles (as can apply when land occupier is different from landowner).

Negligence

Negligence can be defined as conduct which involves an unreasonably great risk of causing damage or as conduct which falls below the standard established by law for the protection of others from unreasonable risk. The basic elements necessary for a cause of action under the negligence theory include: 1) a duty to protect the plaintiff from injury; 2) breach of this duty; 3) proximate cause if the injury or damage, in fact, results from a breach of this duty; 4) actual, not nominal, injury or damage sustained. Under the negligence theory the statute of limitations normally does not begin to run until some damage has occurred or until the damage is discovered.

As shown in the previously cited breakdown, the theory of negligence is most often applied in relation to bodily injury. Generally, the owner or operator of a mine is liable for personal injuries of which his negligence is the proximate cause. In the case of post-closure damage liability it can be very useful in instances of personal injury when due to improper closure methods. An example is neglecting to properly cover or seal an abandoned shaft, thereby resulting in injury to persons or animals which happen to accidentally fall through the opening. However, as stipulated in the four elements necessary to maintain a cause of action for negligence, not only must proximate cause be shown, but also there must be a legal duty to protect the injured party. In connection with this, it is usually the case that no legal duty exists towards a trespasser to keep mined lands in a safe condition, other than to refrain from willfully or wantonly injuring him. This point of the relationship of the parties (trespasser, invitee, licensee) is often a determining factor in establishing liability in such cases. Another element which often centers into the determination of liability is defining what constitutes effective closure. As delineated in Tables 4 and 5, federal and state regulations often dictate simply closing and/or fencing mine openings upon closure. Although this may be interpreted differently in different jurisdictions, it often is interpreted to imply a legal duty to merely prevent an inadvertent or unintentional entry. It usually does not imply closing or fencing a mine opening in such a manner as to make it impossible for persons to enter under any circumstances.

Negligence per se

Negligence per se applies when an unexcused breach of a statutory or regulatory duty results in injury or damage. It is interpreted by the courts that the statute fixes a standard or duty from which it is declared negligence to deviate. In general, when dealing with negligence per se, the courts tend to associate with the statute involved (the same type of liability related to its common law counterpart). Normally, if a statute imposes no specific penalty or only a criminal penalty, then under negligence per se civil liability may still be imposed; in addition, civil liability may also be imposed beyond that specified in a statute.

Liability under negligence per se usually requires no more than to show that the failure or breach of statutory or regulatory duty by the mine operator was intentional, rather than to show an evil, wanton, or malicious intent. It is also a general rule that a mining company is liable for a violation of a statute by its employees, independent of any knowledge of this by its officers. As displayed in the previously cited breakdown, negligence per se is often applied in relation to all three general categories of post-closure damage liability - acid mine drainage, subsidence, and bodily injury damage - in accordance with the types of statutes listed under each respective catetory (i.e. public nuisance statutes and water quality regulations under acid mine drainage; subsidence control statutes or regulations under subsidence damage; mine closure statutes or regulations under bodily injury).

Nuisance

Common law nuisance has been applied to a wide diversity of situations, and is therefore incapable of being exactly or comprehensively defined. However, it basically means the unreasonable use of property in such a way as to cause injury, damage, discomfort, inconvenience, or annoyance to another in the legitimate enjoyment of his rights of person and/or property. It includes doing an act or omitting to perform a duty thus damaging , injuring or endangering the comfort, health, or safety of others or their property. The difference between private nuisance and public nuisance does not depend so much upon the nature of the nuisance itself, but rather upon who is affected. A private nuisance is one which affects a party personally as distinguished from the public generally. Coversely, a public nuisance affects the public generally rather than a specific person or persons. Nevertheless, a person or persons specially affected by a public nuisance may initiate proceedings on the basis of a private nuisance. Remedies for nuisances generally fall into three categories:

1) Action at law for all damages which have been suffered including nonmaterial damage (as for discomfort, annoyance, and inconvenience)
2) Equitable relief by injunction
3) The privilege of summary abatement by self-help

The latter remedy applies only to a person or persons for which the condition is actually a nuisance and gives them the right to enter another's land and in a reasonable manner terminate the nuisance. Usually this applies where there is no time to resort to legal process. However, if the self-help action initiated is unjustified, even an honest belief will not provide protection to the one using the remedy from criminal prosecution or civil liability. Normally, the statute of limitations for a nuisance does not begin to run until substantial harm results.

A different kind of nuisance is the statutory nuisance - a statutory repose to the inadequaties or uncertainties of common law remedies. An example is public nuisances designated specifically as such by statute. Examining by the courts for negligent conduct or unreasonable use is generally precluded by this type of nuisance. Furthermore, where a criminal penalty is prescribed in the nuisance statute, an additional remedy to common law nuisance is offered in the form of criminal prosecution of the offender.

Although mining is a lawful and necessary business and a reasonable use of property and is not a nuisance per se. It may, however, like any other business, become a nuisance by reason of the manner in which it is conducted.

As pointed out in the previously cited breakdown, the nuisance theory most often is associated with acid mine drainage damage. Established principles of law relating to pollution of waters are applicable to mine drainage pollution and the basis of liability is generally that pollution constitutes a nuisance. Therefore, it is not ordinarily material that the mining operation was conducted according to custom or without negligence. Another applicable legal generality is that each owner of land abutting stream water is said to have a riparian right to use such water so long as he does not interfere with its reasonable use by other landowners. When mine discharges interfere with the reasonable use of water by others, it constitutes an actionable nuisance. However, this rule of reciprocal reasonable use, as is the case for most common law theories or rules, is too abstract to accurately predict the court outcome. In determining whether the injury is of such a substantial character as to sustain a cause of action, the extent of the injury is often not considered alone. Rather, it may be considered in conjunction with the character of the neighborhood and other surrounding circumstances, such as the importance of the mining industry to its particular community and even to state at large. In some circumstances, the private or individual interests are thereby subordinated to those of the public.

In the realm of public and statutory nuisances, mine operators are considered to have no property right, as against the public, to discharge mine water into public streams so as to render it unfit for public use. However, under some water pollution control statutes the administrative procedure for handling a pollution problem may be exclusive, precluding the state attorney general from suing for the abatement of a public nuisance. One substantial legal problem does arise if a public nuisance statute is used in an effort to compel a private landowner to upgrade his property (e.g. mine sealing), particularly if he did not participate in the previous mining. For regulation of private land use in this type of case may come close to and even cross the thin line between an acceptable exercise of a state's police power and violation of a property owner's constitutional rights. In connection with this problem, state officials contacted during this study often expressed their concern with the problem of financial inability or insolvency in attempting to place the burden of liability and force the owners of a parcel of land which contains an underground mine to seal the abandoned opening.

In an issue related to mine drainage and water problems, mining operations which intercept or draw away percolating waters thereby resulting in injury to other property owner's wells or springs, generally do not, in most jurisdictions, make the operator liable unless it is the result of: 1) pollution from failure to comply with a statute requiring mine drainage to be contained; 2) negligence; 3) subsidence caused by lack of proper subjacent or lateral support; or 4) operations which the mine operator knew or should have known could cause such injury.

Subjacent or Lateral Support

Subjacent support applies to the surface land directly above the mine, and the doctrine of subjacent support is only applicable where the surface estate is, by deed or otherwise, severed from an underlying mineral estate having a different ownership. Under this doctrine, the owner of the surface rights is entitled to absolute support, as a proprietary right at common law, unless otherwise stipulated by contract or conveyance. Furthermore, this stipulation must be clearly indicated in such an agreement. This right is without regard to the comparative value of the mineral strata removed versus that of the damaged surface land, and is strictly liable in that liability results irrespective of actual negligence in conducting the mining operation. Moreover, custom among miners, such as pillar robbing, is generally not a defense. Since subjacent support is strictly liable it is an absolute right, and the duty of support is thereby an absolute duty; because of this, it is normally considered immaterial as a defense that the minerals have been removed carefully and skillfully and by means of an approved system of mining.

In addition to the surface land, it is generally agreed that structures existing or contemplated at the time of the severance of the surface and mineral estates are also entitled to support. This is either directly viewed as such by the courts or indirectly by placing the burden of proof on the operator that the subsidence would not have occurred without the added weight of the structures. However, in some jurisdictions an opposing view is held and the surface owner can recover for damage to his structure only if it can be shown the mine operator negligently removed the subjacent support.

In general, damages for permanent injury are measured by the difference in market value of the premises before and after the injury, while the measure of damages for reparable injury is the cost of repairs. This applies to reparable injury as long as the cost is not greater than the diminution in value of the premises; when that is the case, the difference in market value becomes the measure. Also, in some jurisdictions, reasonable compensation for the loss of the use of the property between the time of injury and that of restoration is added.

Lateral support applies to neighboring surface land adjacent to that directly above the mine. Generally, these same positions noted in the subjacent support discussion apply to lateral support liability cases, though in some jurisdictions, it seems more difficult to recover for damages to land encumbered by buildings.

Breach of Contractual Duty and General Leasehold Principles

Little specifically can be said about breach of contractual duty other than to point out that the contract between the miner and owner of land and/or mineral rights often is a critical factor in determining liability for damages. The specific wording contained in each contract is often used by the courts in determining such cases.

Under general leasehold principles in many states, a lessor (landowner or mineral rights owner) is not responsible for wrongs committed by his tenant (mine operator) during the term of the lease unless he has: 1) participated in the wrong; 2) supervised the tenant's activities; or 3) retained control over the tenant's activities. However, in some jurisdictions, the continous receipt of benefits by the lessor (landowner or mineral rights owner) in the form of royalties and rents seems to be the basis for justifying and imposing liability upon the lessor for harm resulting from the conduct (mining) which produces the royalties or rents. This seems to be true particularly where the lessor makes no attempt to limit such conduct in the lease and the lessor knew or should have known such damage would result from the lessee's mining activities. However, another consideration previously discussed, that of financial inability or insolvency, often becomes a critical factor, at least when the liability burden is extreme.

The liability of a vendee for nuisances existing on the land at the time he purchases the property, under general principles, does not preclude the vendee's responsibility, even though he did not create the condition; at least, he may be liable if: 1) he takes possession; 2) the condition is abatable; and 3) he has had a reasonable opportunity to discover this condition. However, in the case of a subsequent mine operator being held liable for problems associated with the conduct of the previous mining company, consideration as to the adverse effect upon remining areas may become an additional factor in determining liability.

Common Law Summary

As evident, the outcome of post-closure damage liability litigation, based upon common law doctrines, is very difficult to predict. As was stated in the beginnning of this section on post-closure damage liability, there are complex legal issues and numerous variables involved in such cases and each case usually comprised different circumstances and variables which may prove relevant in determining liability. Because of this unpredictability of such common law based cases, the fact that adversary proceedings are so cumbersome and expensive, and the history of the courts in not being willing, in general, to impose liability on persons other than the actual mine operator (who seldom can be found in a state of financial solvency after mine closure) little litigation has resulted in this area. It is basically due to this seeming inability of common law to control the problems associated with mining and the fact that federal and state legislative intervention has resulted in statutory responses complemented by governmental agency regulations concerning these problem areas.

Statutory Responses

The following are general avenues of approach utilizing specific statutory responses which directly or indirectly might prove relevant in establishing liability in post-closure damage cases. Included are those suggested by various state legal counselors contacted during this study.

An example of one of the more direct types of statutes found affecting this area of post-closure damage liability is Section 45-4-14 of the South Dakota Compiled Laws, Volume 7, which states:

> "Every person, firm, association or corporation who may hereafter make or sink discovery shafts, open cuts, adits or equivalents thereto, upon any mining claim, or on any mineral property, ground or premises shall forthwith, while using the same, make them secure and safe in a manner, either by means of substantial fence or otherwise, so as to guard against the possibility of livestock falling into or in any manner becoming injured or destroyed by reason of such openings; and before abandoning the same, shall fill in or slope such openings, as a further precaution. Every person, firm, association or corporation that shall fail or refuse to fully comply with the provisions of this section shall be liable in damages for injury to or destruction of livestock caused thereby to the owner thereof and shall further be guilty of a misdemeanor and, upon conviction thereof, shall be punished by a fine not to exceed one hundred dollars or by imprisonment in the county or municipal jail for not more than thirty days or by both such fine and imprisonment"

A similar type of statute is found in Wyoming Statutes, Volume 7A, W.S. 30-23, which provides for stiffer penalties by allowing a 90-day period of incarceration and, in addition, imposing liability for any damages sustained by injury or loss of livestock to the owner. It reads:

> "Every person, persons, company or corporation, who have already sunk mining shafts, pits, holes, inclines, upon any mining claim, or upon any mineral property, ground or premises, or who may hereafter sink such openings aforesaid, shall forthwith secure such shafts and openings against the injury or destruction of livestock running at large upon the public domain, by securely covering such shafts and other openings as aforesaid, in a manner to render them safe against the possibility of livestock falling into them or in any manner becoming injured or destroyed thereby;or by forthwith making a strong, secure and ample fence around such shafts and other openings aforesaid. Any person, persons, corporation or company who shall refuse to fully comply with the provisions of this section shall be guilty of a misdemeanor, and on conviction thereof shall be subject to imprisonment in a county jail for not more than ninety days or fine of not more than one hundred dollars ($100) or both such imprisonment and fine in the discretion of the court imposing sentence. Any person, persons, corporation or company who shall fail or refuse to fully comply with the provisions of this section shall also be liable to the owner thereof for any damages sustained by injury or loss of livestock thereby".

The Annotated California Code, Volume 41, Section 24400 declares that failure to cover, fill, or fence securely any abandoned excavation and to keep it so protected by a person owning land in fee simple or in possession thereof under lease or contract of sale is guilty of a misdemeanor. Similarly, Section 45-8-113, Volume 8, of the Montana Code Annotated states that a person being the owner or otherwise having possession of property upon which there exists a mine shaft or other hole of a depth of $\geq$ 4ft and top width $\geq$ 12" commits the offense of creating a hazard if he knowingly fails to cover or fence it with a suitable protective construction; it mandates a fine not to exceed $500 or imprisonment not to exceed 6 months, or both.

An example which may be applied in determining post-closure damage liability is found in California's Partner-Cologne Water Quality Control Act, Section 13305, states that upon determining a condition of pollution or nuisance is from a nonoperating industrial location, a regional water quality control board may require it to be abated; otherwise, at the property owner's expense, it will be abated by the appropriate public agency. Seemingly this includes abandoned mines, and a section in one of California's Regional Water Quality Control Plan Reports indicates the policy of making the landowner bear the cost of source control measures for abandoned mines. This type of abatement by a public agency is a form of abatement by self-help which was explained previously in the common law discussion. A similar self-help type of provision is found in Section 316 of Pennsylvania's Clean Streams Law in that when a landowner or occupier does not correct a condition causing pollution or a danger of pollution from an abandoned mine after being ordered to do so, an agency of the Commonwealth is permitted access to take such action and the expense is recovered by assessing a civil penalty.

There are also other, more general state statutes which might be applicable. The general "right of action for injuries" clause often found in state mining codes usually applies for any injury to person or property caused by willful failure to comply with state mining laws and regulations and holds the person or company operating the mine as liable for damages. Although these are generally used in active mine injury or damage cases, they might broadly be interpreted to apply to such instances as a bodily injury case after mine abandonment when there was a willful failure to cover or seal a shaft opening as dictated by state requirements. An example of this "right of action for injuries" clause is found in Section 30-141 of the Coal Mining Laws of the State of Wyoming, and it states:

> "For any injury to person or property occasioned by any violation of this chapter, or any willful failure to comply with its provisions, a right of action against the party at fault shall accrue to the party injured for the direct damages sustained thereby, and in any case of loss of life, by reason of such violation or willful failure, a right of action against the party at fault shall accrue to the administrator of the estate of the person whose life shall be lost, for like recovery of damages for the injury sustained; provided, that nothing in this section shall be so construed as to prevent the recovery of any lawful damages against the person or company operating mines if said company should be found in fault or shall have contributed to any accident by means of carelessness on their part; and provided, further, that in no case shall the state be liable for damages under this chapter".

A general type of statute which might be useful in acid mine drainage related cases is usually found in state water laws; it normally declares a person responsible for pollution related damage to fish, wildlife, or habitat to be liable for costs in restoring the damaged resources.

Another related type of statute, the "statutory nuisance", also might apply to acid mine drainage related cases; and these generally declare pollution of state waters to be a public nuisance. In addition, there may also be other legal conditions defined in the nuisance related portion of the statutes such as those contained within the South Dakota Compiled Laws, Annotated, Volume 7, Chapter 21-10, which after defining public and private nuisances, state a public nuisance cannot be legalized by a lapse of time (Section 21-10-4). Enumerated are the following remedies against nuisances

(Section 21-10-5): 1) civil action and 2) abatement. For public nuisances only, the additional remedy of indictment or information as prescribed by statute and rules relating thereto; permit a public nuisance to be abated without civil action by an authorized public agent or any private person, if the public nuisance is especially injurious to him or if it is a private nuisance (Section 21-10-6); allow for recovery of damage for past injury after abatement (Section 21-10-7); and stipulate that every successive owner of property who neglects to abate a continuing nuisance upon such property is liable in the same manner as the one who created it (Section 21-10-8). Another example is located in the Tennessee Code Annotated, Volume 12A, Section 70-336 which after declaring that pollution constitutes a public nuisance, further states that a plea of financial inability to prevent, abate, or control this pollution shall not be a valid defense.

Some other specific examples are found in Tables 4 and 5 which pertain to federal and state regulations related to underground mine closure. First, it should be noted that the bonding section of the tables may indicate possible mine operator post-closure damage liability. For example, Maryland bonding liability may extend for as long as 5 years after mine closure. Moreover, Pennsylvania may require posting of bond until the regulatory authority determines there is no further significant risk of a pollutional discharge and may require, under certain circumstances, a subsidence bond for a period of 10 years after mine closure. Another Pennsylvania regulation found in Table 5 which might be applicable is a section in Pennsylvania's Clean Streams Law which defines a mine discharge to include post-closure discharges and indicates the mine operator is responsible. Additionally, another previously cited section of this law (Section 316), which applies after the bonding period is terminated, stipulates the landowner or occupier of land from which pollution or a danger of pollution results is responsible to correct the condition or pay a civil penalty and allow an agency of the State access to take such action. For the purpose of this section, a landowner is stated as including any person holding title to or having a proprietary interest in either surface or subsurface rights.

Lastly, it might be possible that state provisions requiring a mine operator to close or protect mine openings can also be broadly construed, depending upon the definition of an operator, to include whoever is in possession of the underground mine and thereby has the right to mine.

Statutory Summary

As can be seen from this discussion on statutory responses which may prove relevant in post-closure damage liability cases, these types of liability issues have not been directly and comprehensively addressed at either the State or Federal government level. Just as for the common law approach, the statutory basis for post-closure damage liability cases involves complex legal issues and numerous variables. The outcome even in statutory based cases seems rather unpredictable for many cases, partly because of the lack of direct and comprehensive statutes related to these issues. As a whole, the legal responses to post-closure damage liability issues up to now are not well established.

MINE CLOSURE METHODS

In the majority of states with underground mining regulations operators of both coal and non-coal mines are required to prevent unauthorized entry into mine openings and protect the public safety. In most states, fences, capping, backfilling and similar prevention measures are the only closure techniques required and initiated.

While safety has been the foremost concern, abandoned mine drainage and subsidence damage, particularly in coal mines, has led many states to implement additional mine closure regulations for environmental protection. In response, numerous techniques have been developed for closing underground mines to control discharge flow and quality, prevent subsidence and provide protection from entry. In the following, these closure methods are discussed under the categories of 1) dry and air seals, 2) hydraulic seals, and 3) temporary closures.

DRY/AIR SEALS

Dry/air seals are restricted to those openings that are accessible to on-site construction, or those that can economically be opened, and are generally restricted to use in areas with stable strata adjacent to the openings.

Dry Seals

A "dry" mine seal is generally defined as a technique used in a location which requires the seal to withstand little or no hydraulic head due to the formation of a mine pool after sealing (i.e., at an "updip" drift, slope, or shaft opening). This type of seal will, however, prevent stormwater surface runoff from entering the underground mine, as well as reducing or preventing the free flow of air into and out of the mine. Several variations of construction are utilized for dry seals.

- Earth Fill Seal for Dry Opening - This was the predominant type of seal used by the U.S. Public Health Service, as well as other federal agencies, under the 1930's federal mine sealing programs. The approach normally taken, during the above sealing program, was to form a dry seal by blasting and caving mine portals. However, when this was impractical, earth fill seals were used. Earth fill seals continue to be the most commonly used type when hydrological considerations are nil, and the primary concern is safety in the form of preventing person and animals from entering the mine. Typical earth fill seals are shown on Figures 1, 2, 3 and 4.

- Earth Fill and Rock Seal for Dry Opening - This was an alternative type of seal, used in place of a simple earth fill seal, when blasting and caving of the mine portal was impractical and a substitute dry seal was required. This type of seal was used predominantly during the federal mine sealing programs of the 1930's. Presumably, a lack of readily available earth backfill would necessitate the construction of the rock bulkhead to support the earth backfill, the quantity of which would approach one-half of the earth required for a simple earth fill seal. Figure 5 illustrates an example of this earth fill and rock seal.

- U.S. Bureau of Mines Dry Seal - In an attempt to evaluate the effectiveness of air sealing on an abandoned, highly acidic drift mine, an air seal of the type shown on Figure 6 was developed and used during a 1965-66 sealing project. Although an actual evaluation of the effectiveness of previous types of dry seals was never conducted, it was judged that this type of seal, with the urethane foam coating and filling would most effectively stop free air circulation into and out of the mine. In this case, a reduction of 3.9% in the oxygen content of the mine was achieved, being reduced from

20.9% to 17.0%. It should be noted that the U.S. Bureau of Mines dry seal concept is effective in preventing casual entry into the mine by persons or animals; however, persons determined to enter the mine could do so with relative ease, due to the thin section presented by the concrete block.

- Dry Shaft Seal Using Concrete Slab - Sealing of a dry shaft with a concrete slab, such as shown in Figure 7, is an alternative method when backfilling of the shaft in its entirety is not economically practical. A more simple version of this without footers was used extensively until about 1952. After a period of time, it was found that the support systems used to form and support the seal would deteriorate, and the seal would become ineffective. Because of these problems, this type of seal has been largely discarded, and greater efforts made to completely backfill shafts. The 1969 Health and Safety Act, however, allows the use of either of the above methods in sealing vertical shafts. The overall effectiveness of this seal was indeterminant at the end of four years of data accumulation; however, it is effective against even the most determined trespass effort.

Air Seals

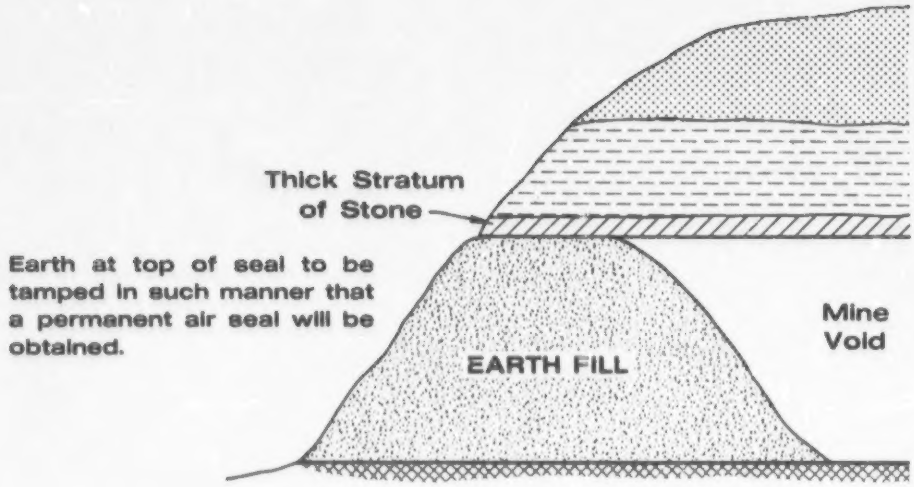
An "air" seal is a modification of the dry seal concept that can be installed in a downdip mine entry to complete the closing off of a mine to elements that cause or expedite the formation of mine drainage pollution by achieving limited mine inundation. After a determination is made as to the configuration of the mine pool required to best reduce pollutant formation, an "air" seal is designed that will withstand the hydraulic head generated by that mine pool, with a drainage mechanism installed therein that will maintain the mine pool at its predetermined, most effective depth. The drainage mechanism will incorporate a water trap such that any exchange of air from the outside atmosphere to the inside of the mine will be prevented. Construction techniques for air seals are generally more complex than dry seals. Some typical examples are:

- U.S. Bureau of Mines Air Seal - This type of seal was used in conjunction with U.S. Bureau of Mines dry seals during a 1965-66 demonstration sealing project in the Commonwealth of Pennsylvania. The objective of this demonstration was to eliminate a highly acid discharge from the mine, through "air sealing." A reduction of 26.5 million liters (7 million gallons) in effluent volume, and a reduction of 150 mg/l in effluent acidity seemed to be attributable to the sealing program. As illustrated in Figure 8, these seals are effective barriers to persons or animals that may inadvertently enter the mine.

- Earth Backfilled Air Seals - This type of seal shown on Figure 9 was installed in five different abandoned coal mines in the state of West Virginia in response to a spring, 1966 fish kill at the U.S. Bureau of Sport Fisheries and Wildlife Fish Hatchery at Bawden, West Virginia.

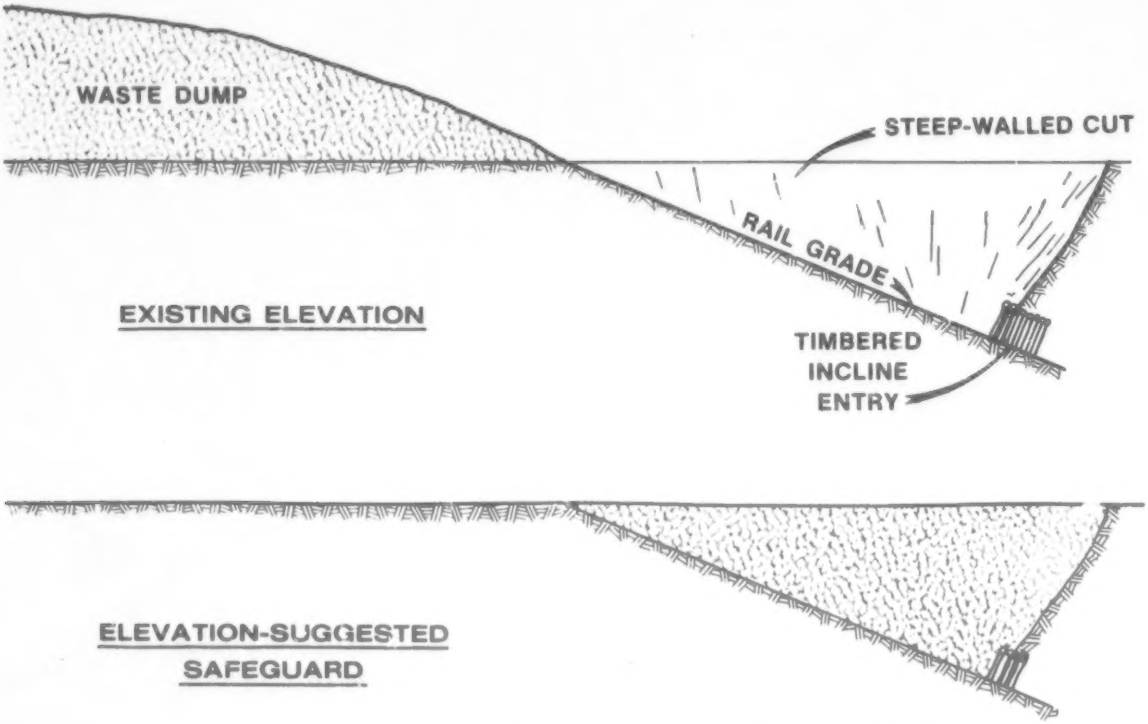
- Clay and Rock Water Trap - Clay and Rock Water Trap seals, illustrated in Figure 10, were used during the 1930's Works Progress Administration (WPA) sealing project, and are the result of an attempt to design an air seal which could be used in unstable areas, and still allow easy water trap cleaning. Another advantage of this seal is that only materials native to the construction site are required. An overall evaluation, on a controlled basis, was never made as to the effectiveness of the 1930's sealing program; however, Pennsylvania, West Virginia, and the U.S. Public Health Service all reported positive benefits from the program.

- Concrete and Water Trap - Mine openings which were continuously flowing, stable in nature, and particularly suited to the formation of a mine pool behind the seal were chosen for this type of seal construction during the 1930's WPA sealing project. No scientific conclusions were reached as to the effectiveness of this type of seal constructed as shown on Figure 11.


Thick Stratum of Stone
Earth at top of seal to be tamped in such manner that a permanent air seal will be obtained.
EARTH FILL
Mine Void

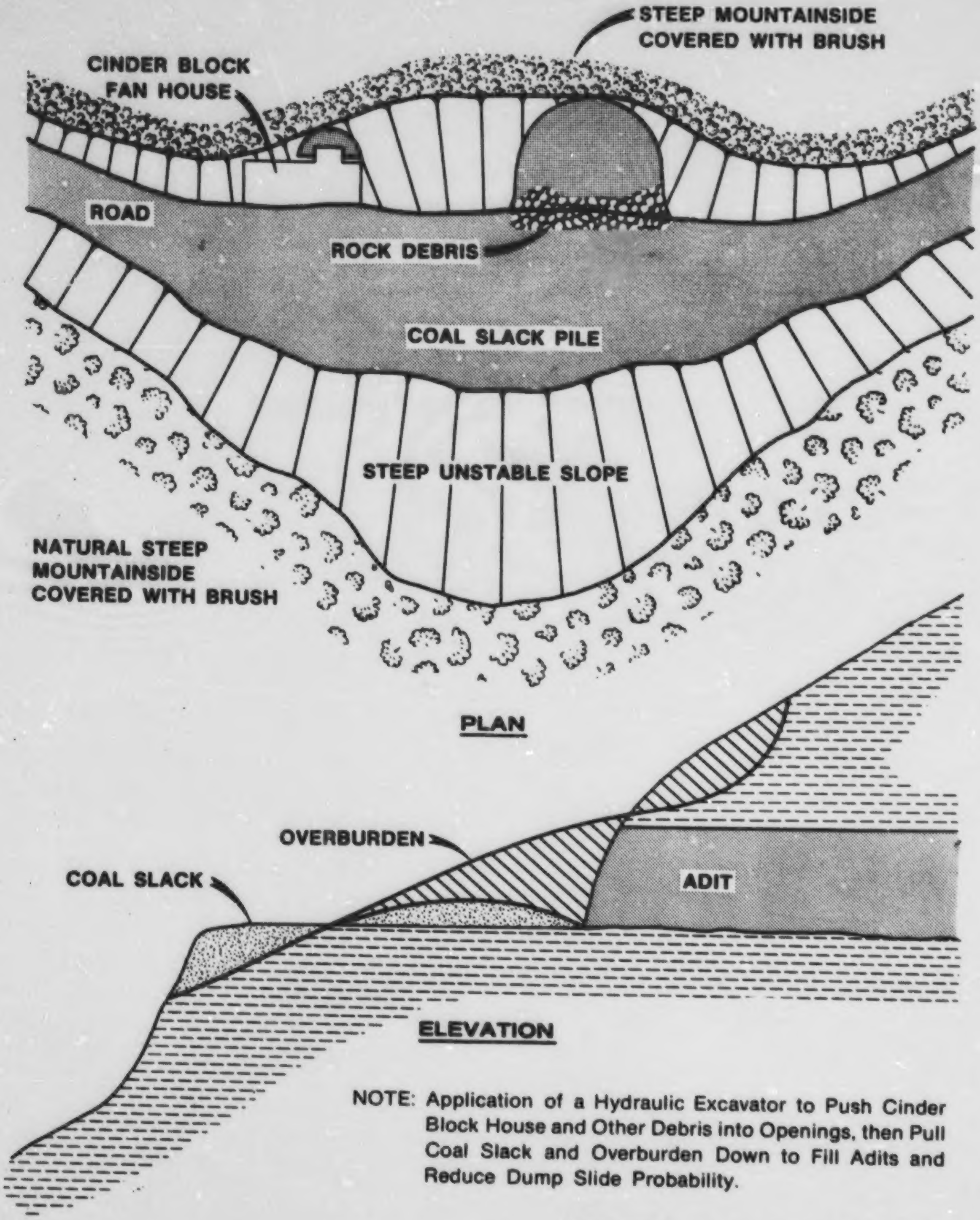
Adapted from Michael Baker, Jr., Inc. (b), 1975

FIGURE 1. - Earth fill seal for dry opening.


WASTE DUMP
STEEP-WALLED CUT
RAIL GRADE
EXISTING ELEVATION
TIMBERED INCLINE ENTRY
ELEVATION-SUGGESTED SAFEGUARD

Source: Skelly and Loy, Engineers-Consultants.

FIGURE 2. - Earth backfill for unstable incline.


STEEP MOUNTAINSIDE COVERED WITH BRUSH
CINDER BLOCK FAN HOUSE
ROAD
ROCK DEBRIS
COAL SLACK PILE
STEEP UNSTABLE SLOPE
NATURAL STEEP MOUNTAINSIDE COVERED WITH BRUSH
OVERBURDEN
COAL SLACK
ADIT

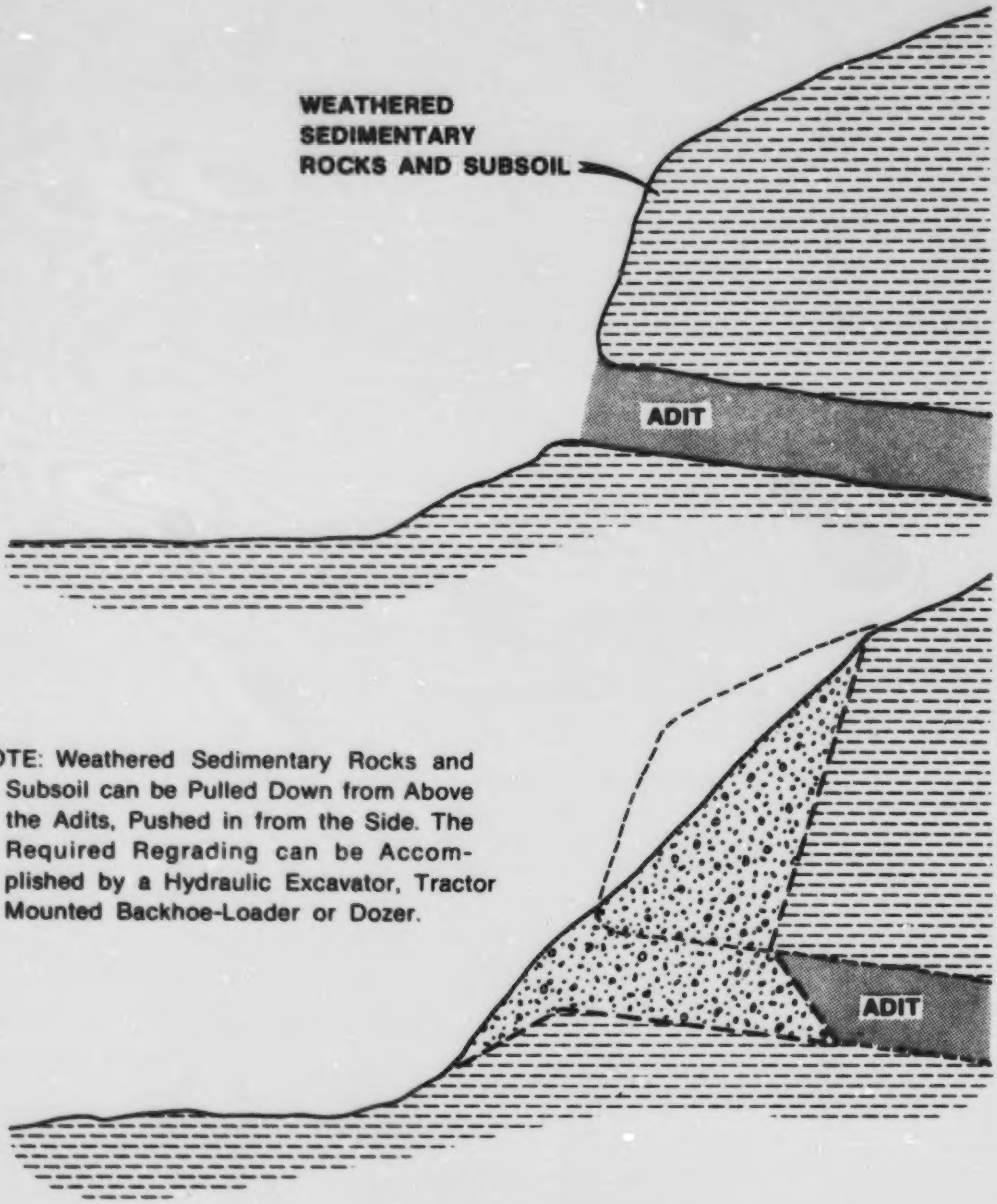
PLAN

ELEVATION

NOTE: Application of a Hydraulic Excavator to Push Cinder Block House and Other Debris into Openings, then Pull Coal Slack and Overburden Down to Fill Adits and Reduce Dump Slide Probability.

Source: Skelly and Loy, Engineers-Consultants.

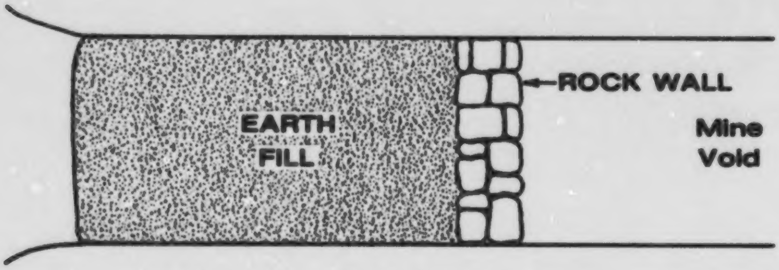
FIGURE 3. - Suggested earth backfill for steep slope adit.


WEATHERED SEDIMENTARY ROCKS AND SUBSOIL
ADIT
ADIT

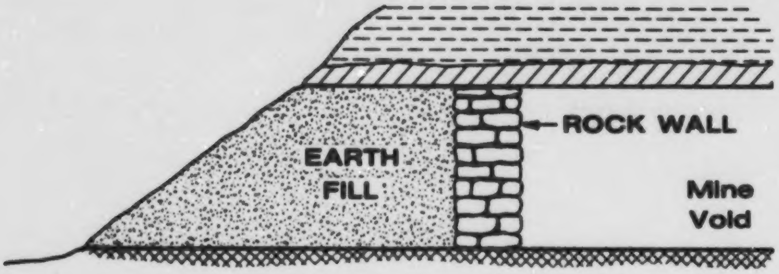
NOTE: Weathered Sedimentary Rocks and Subsoil can be Pulled Down from Above the Adits, Pushed in from the Side. The Required Regrading can be Accomplished by a Hydraulic Excavator, Tractor Mounted Backhoe-Loader or Dozer.

Source: Skelly and Loy, Engineers-Consultants.

FIGURE 4. - Suggested earth backfill for small unstable adit.


EARTH
FILL
ROCK WALL
Mine
Void

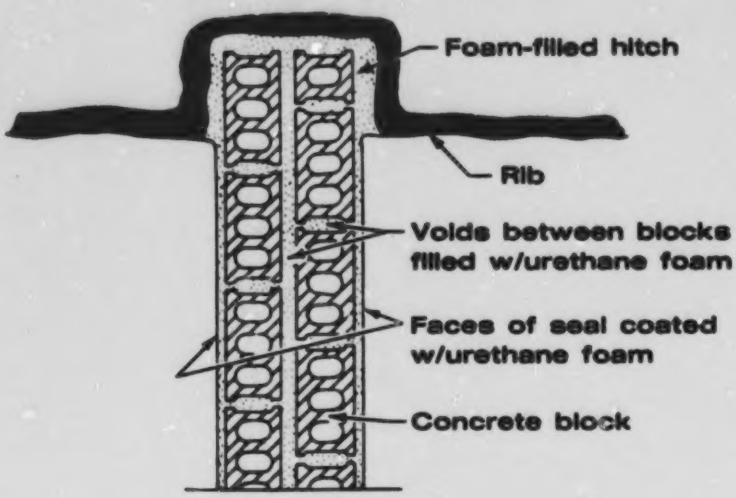
PLAN


ROCK WALL
EARTH
FILL
Mine
Void

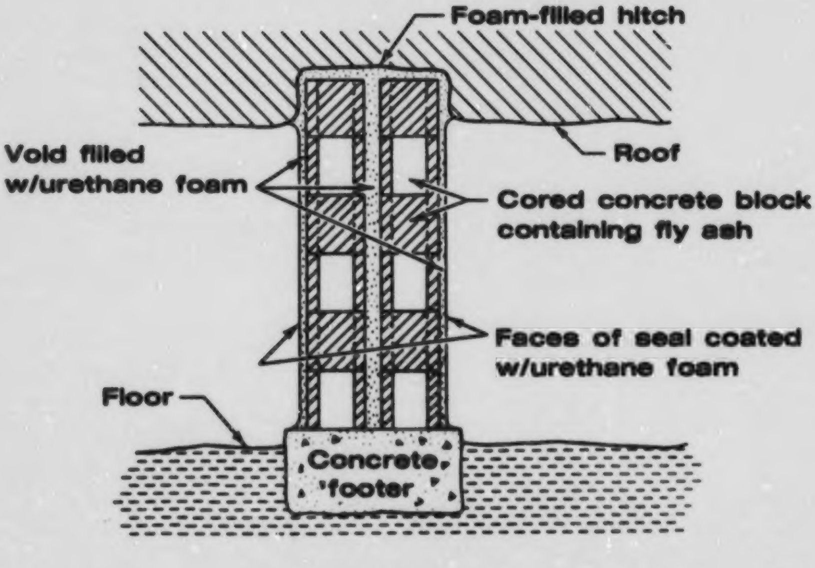
ELEVATION

Adapted from Michael Baker,
Jr., Inc. (b), 1975

FIGURE 5. - Earth fill and rock seal for dry opening.


Foam-filled hitch
Rib
Voids between blocks filled w/urethane foam
Faces of seal coated w/urethane foam
Concrete block

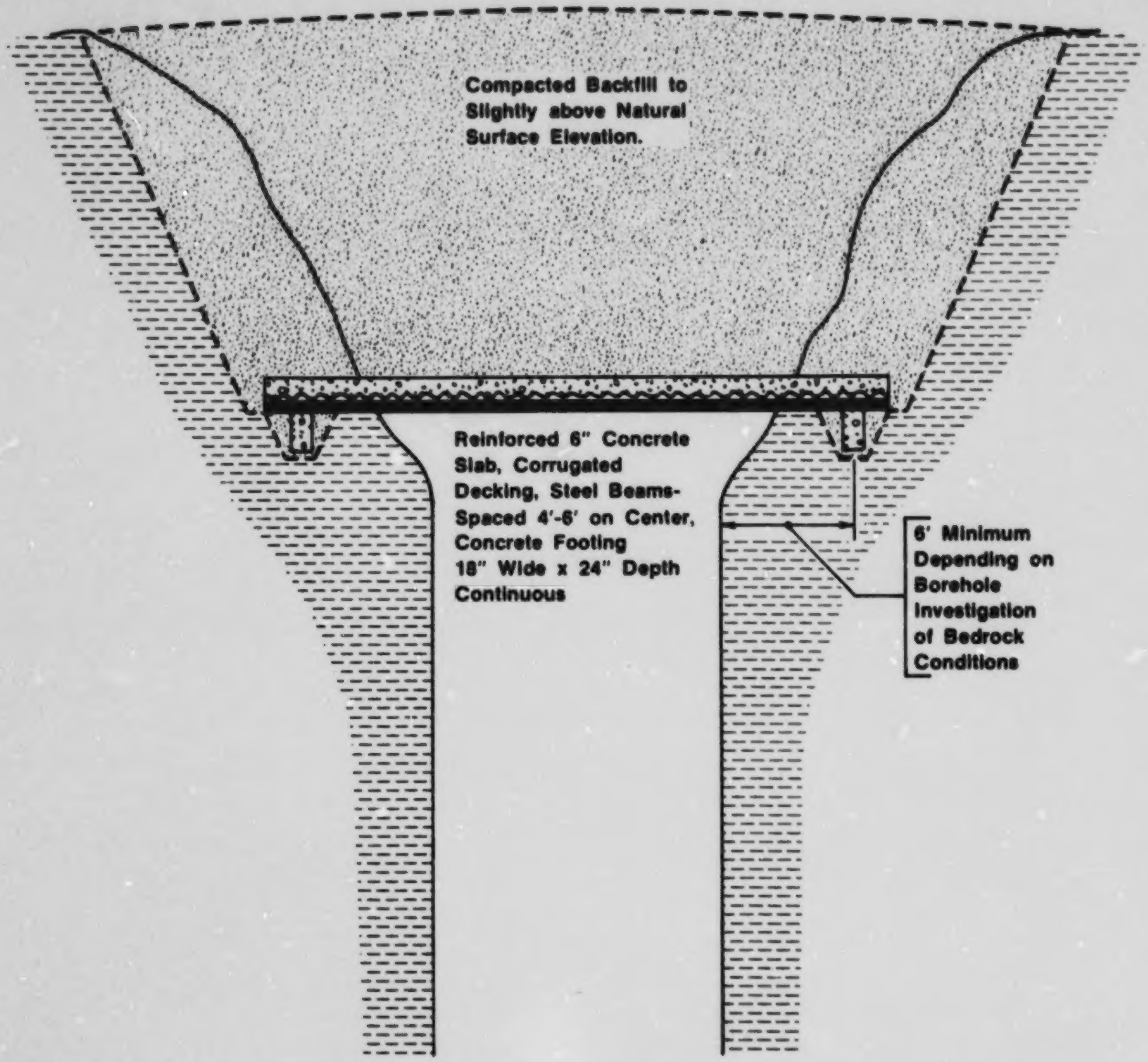
PLAN


Foam-filled hitch
Roof
Void filled w/urethane foam
Cored concrete block containing fly ash
Faces of seal coated w/urethane foam
Floor
Concrete footer

SECTION

Source: Michael Baker, Jr., Inc. (b), 1975

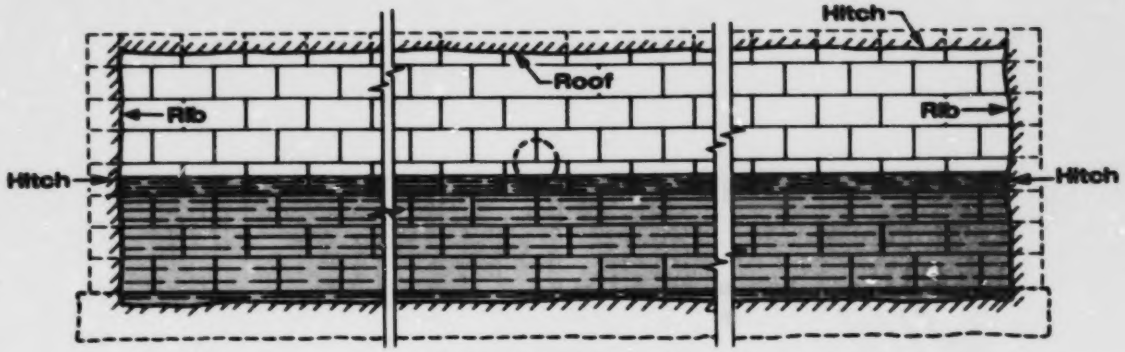
FIGURE 6. - U.S. Bureau of mines dry seal.


Compacted Backfill to
Slightly above Natural
Surface Elevation.
Reinforced 6" Concrete
Slab, Corrugated
Decking, Steel Beams-
Spaced 4'-6' on Center,
Concrete Footing
18" Wide x 24" Depth
Continuous
6' Minimum
Depending on
Borehole
Investigation
of Bedrock
Conditions

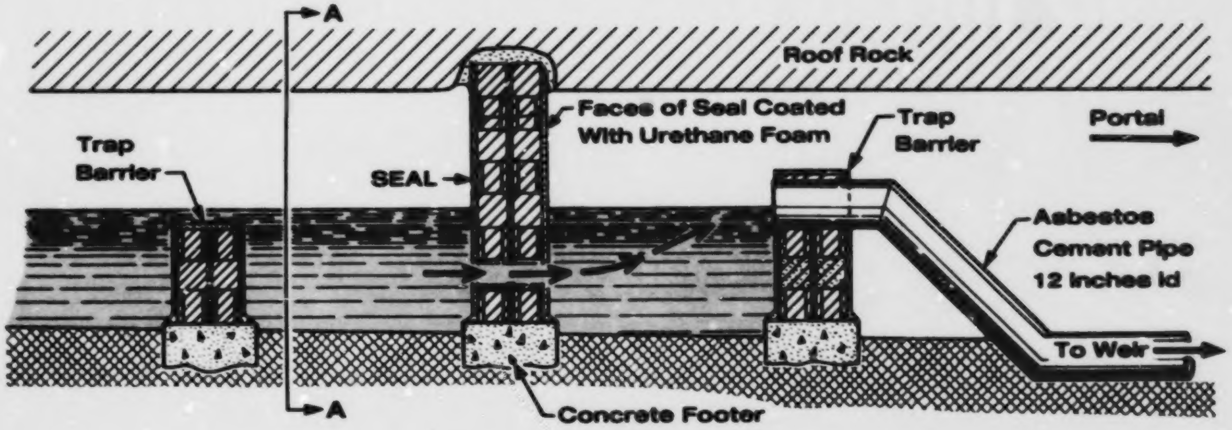
NOTE: Costly Problems Could Arise During Construction (OSHA Could Require Net or Barricade Installed Temporarily to Protect Men Working in or Near Deep Hole. Sloughing Sidewalls Could Slow or Wreck Construction, a Shallow Foundation Test Hole Would be Needed.)

Source: Skelly and Loy, Engineers-Consultants.

FIGURE 7. - Shaft seal with concrete slab.


Hitch
Roof
Rib
Rib
Hitch
Hitch

ELEVATION "A-A"


A
Roof Rock
Faces of Seal Coated With Urethane Foam
Trap Barrier
Portal
Trap Barrier
SEAL
Asbestos Cement Pipe 12 Inches Id
To Weir
A
Concrete Footer

Source: Michael Baker, Jr., Inc. (b), 1975

FIGURE 8. - U.S. Bureau of mines air seal.

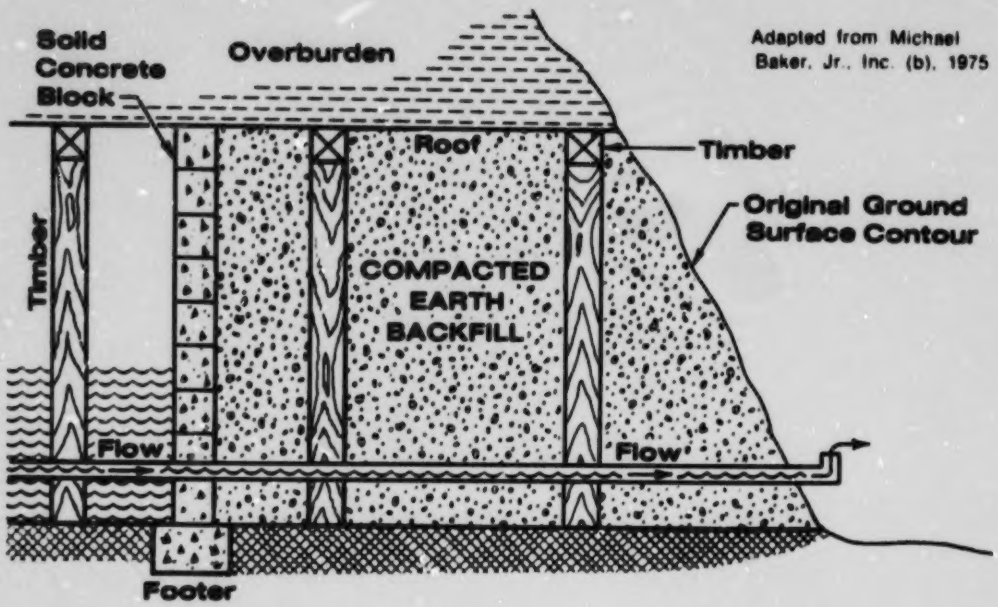

Solid Concrete Block
Overburden
Adapted from Michael Baker, Jr., Inc. (b), 1975
Roof
Timber
Timber
Original Ground Surface Contour
COMPACTED EARTH BACKFILL
Flow
Flow
Footer

FIGURE 9. - Earth backfill air seal.

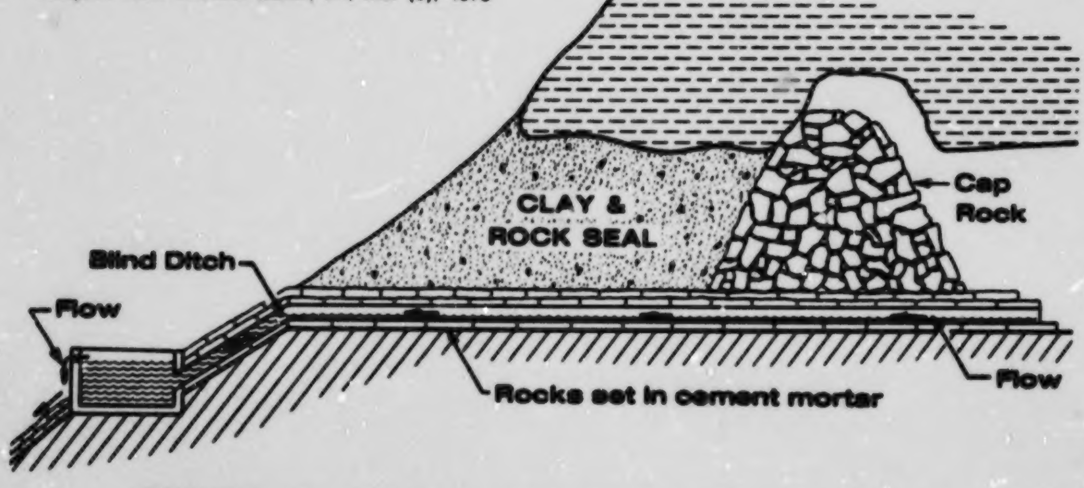
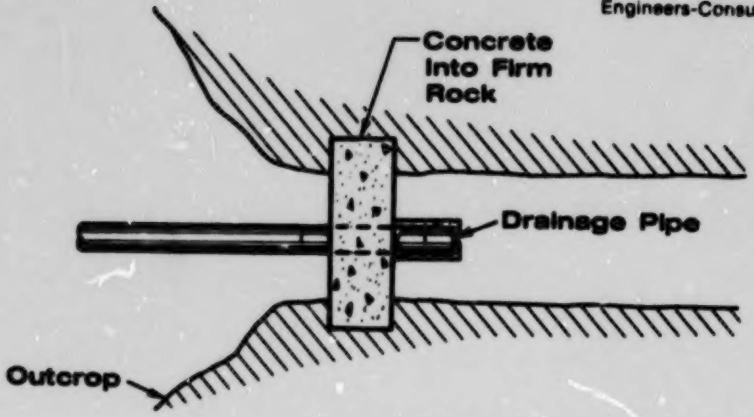
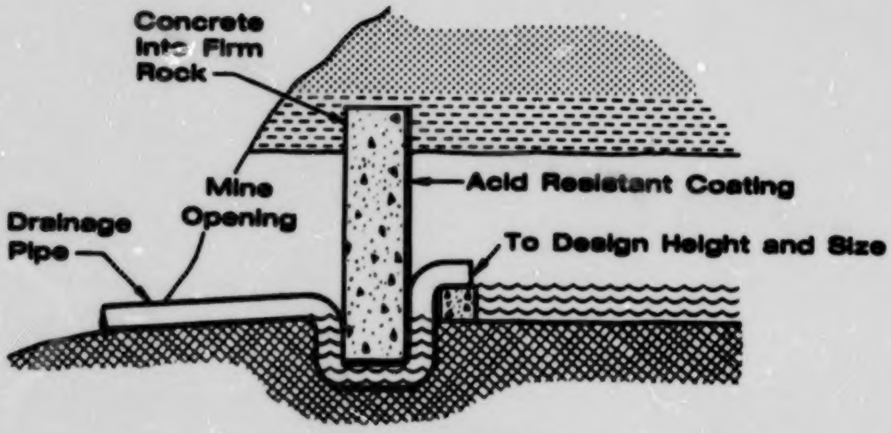

Adapted from Michael Baker, Jr., Inc. (b), 1975
CLAY & ROCK SEAL
Cap Rock
Blind Ditch
Flow
Flow
Rocks set in cement mortar

FIGURE 10. - Clay and rock water-trap air seal for caved pit mouth.

Adapted from Skelly and Loy, Engineers-Consultants, 1973


Concrete
Into Firm
Rock
Drainage Pipe
Outcrop

PLAN


Concrete
Into Firm
Rock
Acid Resistant Coating
Mine
Opening
Drainage
Pipe
To Design Height and Size

SECTION

FIGURE 11. - Trap air seal.

HYDRAULIC SEALS

Hydraulic seals are those closures creating an underground impoundment in which the seals and the mine walls — barrier and outcrop pillars — serve as a dam. The success of hydraulic sealing depends upon the ability of the entire dam structure to withstand water pressure and control mine water seepage. Properly designed and constructed hydraulic seals are capable of withstanding hydraulic heads in excess of 304.8 m. (1000 ft.) (Foreman, 1971).

Hydraulic seals are divided, in the following discussion, into three (3) types - double bulkhead, single bulkhead and multi-purpose.

Double Bulkhead Seal

Double Bulkhead seals were developed to satisfy three criteria: First, an effective seal is needed that will withstand high hydraulic heads. Second, the seal must be capable of being constructed remotely. Thirdly, due to the nature of remote construction, no timbering or other means of supplementary reinforcement of the strata surrounding the seal would be possible, therefore the seal must be capable of withstanding shifting earth pressures.

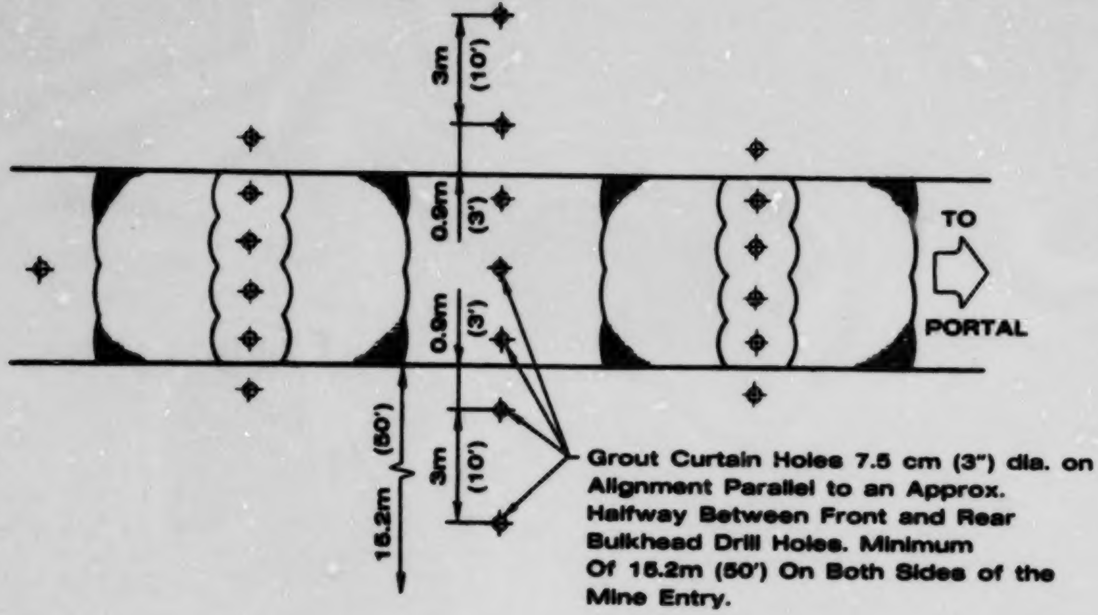
This type of seal is used when a complete "watertight" sealing of a caved, inaccessible mine opening is attempted. Seals of lesser potential integrity, and cost, are generally used for the less critical seals, located at higher elevations, with double bulkhead seals employed at the head of the underground mine pool as a "dam" or "plug".

Double bulkhead seals are generally constructed by one of two methods. The first method employs the hydraulic placement of two crushed stone "bulkheads" at a predetermined spacing in the mine opening tunnel, subsequent grouting of the stone bulkheads to achieve a watertight condition; and the introduction of a cementing material into the space between the bulkheads to create a watertight, solid seal. A second, similar method of construction utilizes the front and back stone bulkheads in an ungrouted condition to retain the center plug. This method results in a seal of potentially less perimeter area watertightness.

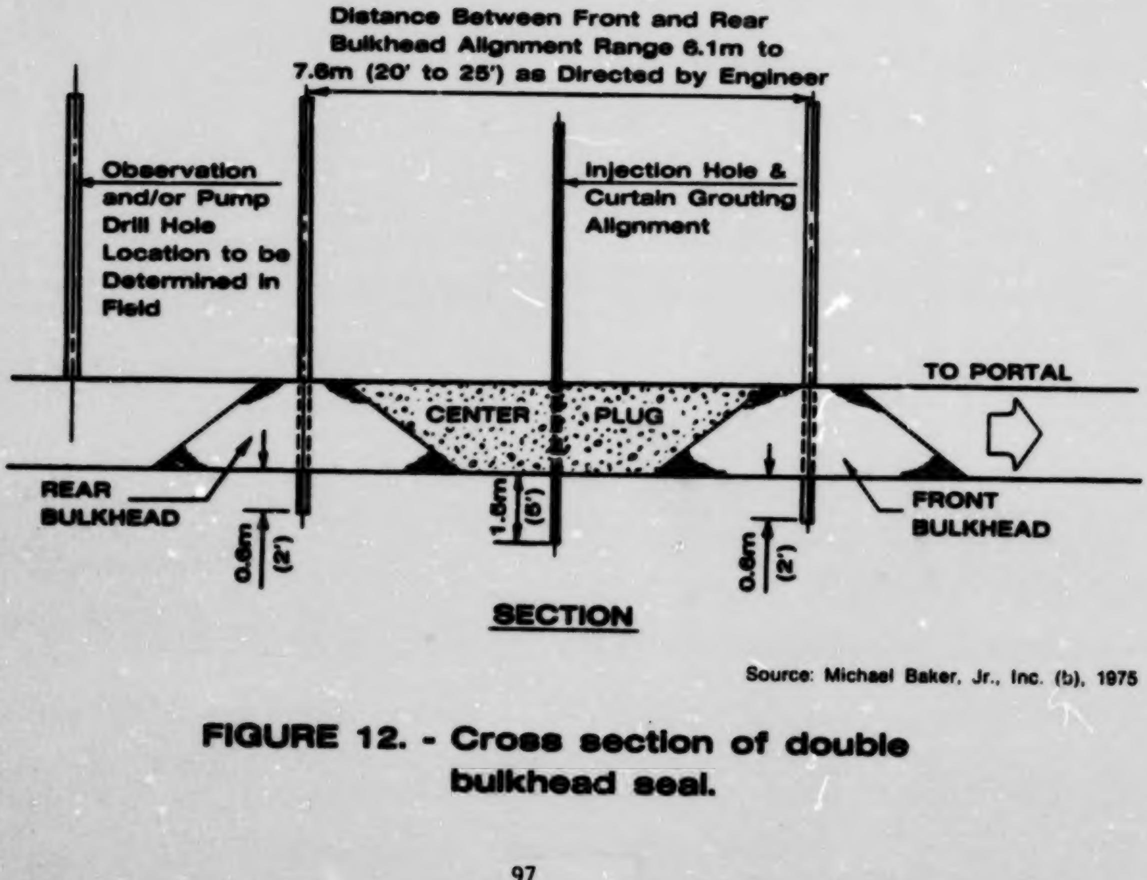
Numerous gradations and types of stone, ranging from locally available quarried stone, to specially selected limestone, to blends or stratified combinations of aggregates, have been or are proposed to be used in double bulkhead seals. Likewise, the type of cementing material used to pack the void between the bulkheads is subject to site specific interpretation as it relates to the "best" mixture to use.

Regardless of the materials used, when placed remotely, the seals are constructed by drilling holes through the overburden directly above the opening to be sealed, and the materials are hydraulically placed in the opening through these holes (Figure 12). These seals can also be placed in assessible entries, but when such conditions exist, a single bulkhead seal is generally viewed as a simpler, less expensive and equally effective alternative.

The double bulkhead seal has exhibited a high degree of effectiveness in reducing acid mine drainage, especially where an entire mine is sealed.


3m
(10')
0.9m
(3')
0.9m
(3')
TO
PORTAL
(50')
15.2m
3m
(10')
Grout Curtain Holes 7.5 cm (3") dia. on Alignment Parallel to an Approx. Halfway Between Front and Rear Bulkhead Drill Holes. Minimum Of 15.2m (50') On Both Sides of the Mine Entry.

PLAN


Distance Between Front and Rear Bulkhead Alignment Range 6.1m to 7.6m (20' to 25') as Directed by Engineer
Observation and/or Pump Drill Hole Location to be Determined in Field
Injection Hole & Curtain Grouting Alignment
TO PORTAL
CENTER
PLUG
REAR BULKHEAD
FRONT BULKHEAD
1.5m
(5')
0.6m
(2')
0.6m
(2')

SECTION

Source: Michael Baker, Jr., Inc. (b), 1975

FIGURE 12. - Cross section of double bulkhead seal.

Single Bulkhead Seal

Single Bulkhead seals come in numerous forms, all of which are designed to withstand hydraulic heads of varying magnitude, and to thereby totally seal off any discharge from an underground mine. The decision as to which form of single bulkhead seal to use can be made only after studying site specific factors such as the accessibility and/or inaccessibility of the opening, the integrity of the rock strata adjacent to the opening, the expected hydraulic head, and the availability of materials.

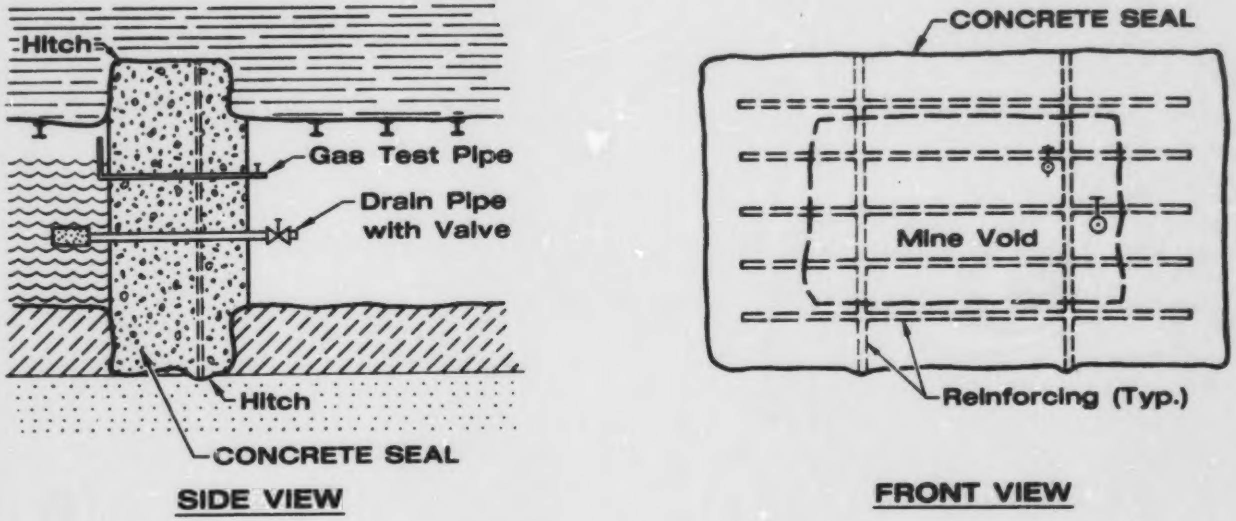
Additionally, several of the single bulkhead seals described below have been tried only on an experimental basis. They are theoretically sound, and their demonstrated failure can more probably be attributed to the site chosen for use than to the "seal" itself.

Therefore, a thorough engineering/geologic evaluation of the proposed mine is imperative if the correct seal is to be chosen.

Single bulkhead seals are usually composed of the following, generally available and economical construction material:

- Poured Concrete - This is the most commonly applied of the "standard" single bulkhead seals (in use since the early 1900's). Garcia and Cassidy (1973) reported that such seals, poured as early as 1926, were capable of withstanding hydraulic heads as great as 49.2 m (161.5 ft.), or 49,217 kgsm (70 psi) (Figure 13).

- Masonry Block or Brick - This type of seal generally requires timber support of the mine roof to prevent pressure from being applied to the seal in the event of roof fall adjacent to the seal. Additionally, reinforcement with steel rods or their equivalent, plus a seal face coating of some acid resisting material is required to prevent deterioration of the seal. Low hydraulic heads must be maintained if this type of


Hitch
Gas Test Pipe
Drain Pipe
with Valve
Hitch
CONCRETE SEAL
CONCRETE SEAL
Mine Void
Reinforcing (Typ.)

SIDE VIEW

FRONT VIEW

Adapted from Michael Baker, Jr., Inc. (b), 1975

FIGURE 13. - Poured concrete single bulkhead seal.

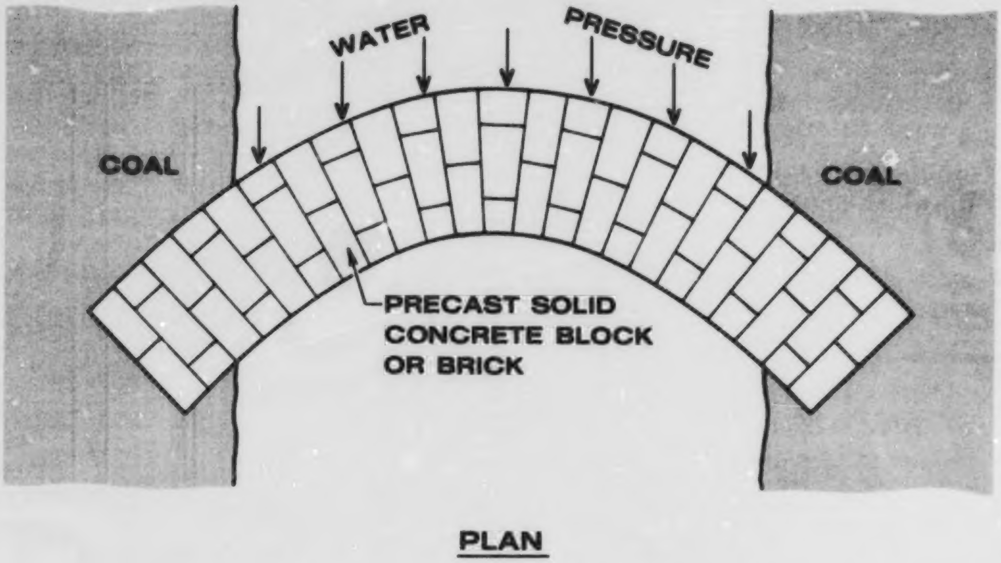
seal is to be successful; however, masonry block or brick seals can be strengthened by placing earth backfill in contact with the seal (Figures 14 and 15).

- Grouted Aggregate - Unlike poured concrete and masonry block, grouted aggregate seals have the advantage of being available for use in either accessible or inaccessible mine openings (Figures 16 and 17). Limestone, from 3/4" to 1½" in size, is placed in the opening, and subsequently grouted by injection of a slurry consisting of various ratios of water, cement, bentonite, and sodium silicate. The aggregate tends to consolidate and slump away from the mine roof during the grouting operation, and additional grout must be pumped into the open space. The maximum hydraulic head contained, to date, by this type of seal is approximately 3 m. (10 ft.). Since an aggregate seal is not keyed to the roof, floor, and sides of the mine opening, pressure grouting of the surrounding strata is usually needed to make the seal homogeneous with the rock and mineral walls.

- Quick Setting/Gel Material - This method of mine sealing has been demonstrated in an accessible mine opening, but the application of a quick setting/gel material seal to an inaccessible area is technically feasible. Quick setting bulkheads are constructed by separately preparing two slurries and pumping them, individually, into the seal site, allowing them to mix at the point that is to be sealed. As the slurries combine, they react with each other and the result is a viscous quick setting material capable of supporting its own weight. The slurries are composed of various ratios of water, cement, bentonite and sodium silicate, as well as chemical grouts such as vinyl polymers. This type of seal has held back a hydraulic head which remained constant at 2.5 m. (8.2 ft.). Figure 14 illustrates an experimental gel material seal.

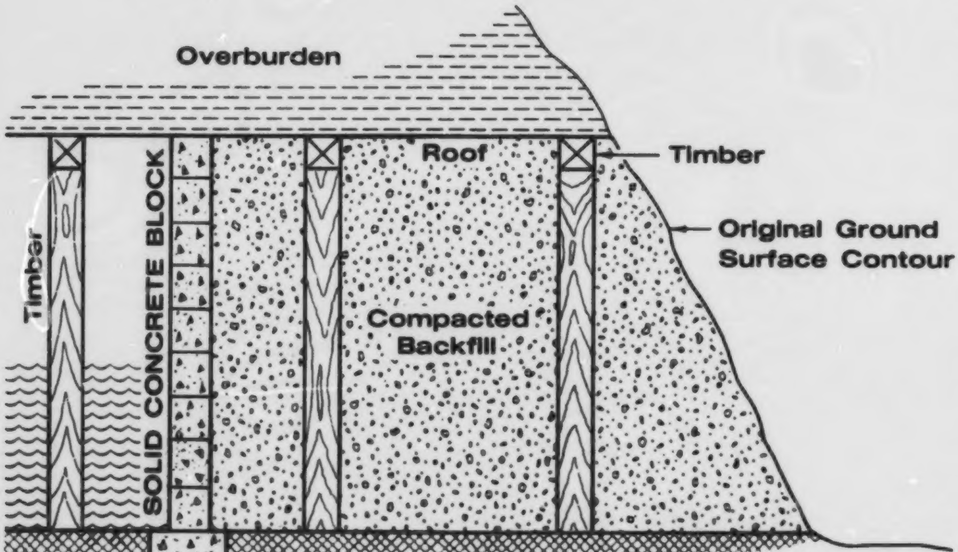
Using the Engineering News Record Index of Construction Cost to update the seal costs to 1979 dollars, a large difference is evident:

- Poured Concrete Seal - $3,200.00 average cost for construction of two bulkheads in the Saxton Mine, near Terre Haute, Indiana. The approximate size was 1.5 m. (4.9 ft.) high x 4.8 m. (15.7 ft.) wide x 3 m. (9.8 ft.) long.


WATER
PRESSURE
COAL
COAL
PRECAST SOLID
CONCRETE BLOCK
OR BRICK
PLAN

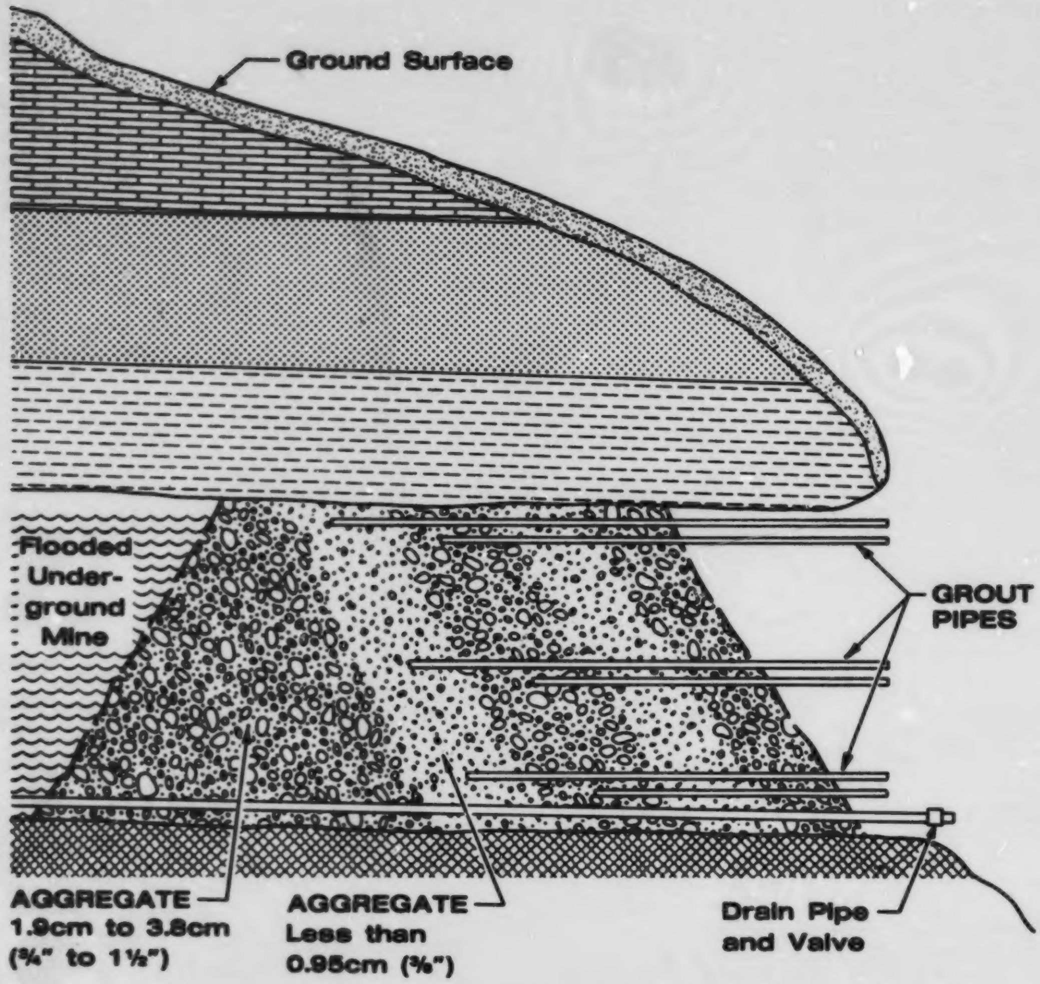
Adapted from Michael Baker, Jr., Inc. (b), 1975

FIGURE 14. - Masonry block or brick single bulkhead seal with curved brattice construction.


Overburden
Roof
Timber
Original Ground
Surface Contour
Timber
SOLID CONCRETE BLOCK
Compacted
Backfill
Footer

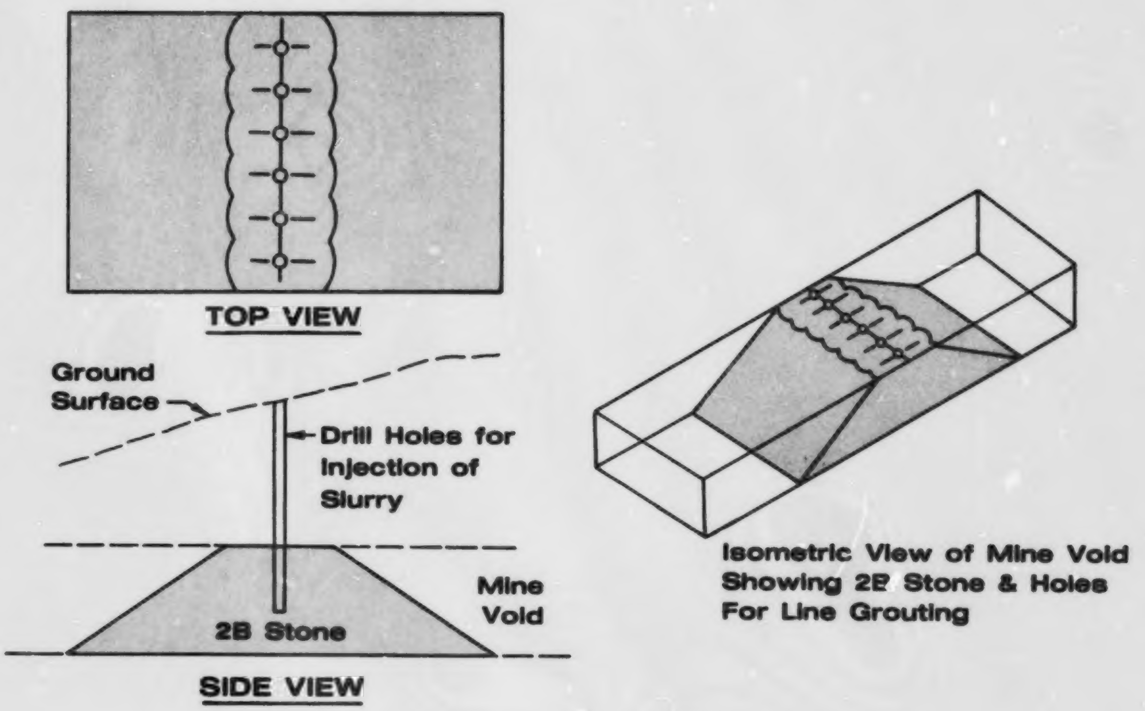
Source: Skelly and Loy, Engineers-Consultants, 1973

FIGURE 15. - Backfilled masonry block seal.


Ground Surface
Flooded Underground Mine
GROUT PIPES
AGGREGATE 1.9cm to 3.8cm (¾" to 1½")
AGGREGATE Less than 0.95cm (⅜")
Drain Pipe and Valve

Adapted from Skelly and Loy, Engineers-Consultants, 1973

FIGURE 16. - Grouted aggregate seal for accessible opening.


TOP VIEW
Ground Surface
Drill Holes for Injection of Slurry
Mine Void
2B Stone
SIDE VIEW
Isometric View of Mine Void Showing 2B Stone & Holes For Line Grouting

Adapted from Skelly and Loy, Engineers-Consultants, 1973

FIGURE 17. - Grouted aggregate seal for inaccessible opening.

Adapted from Michael Baker, Jr., Inc. (b), 1975

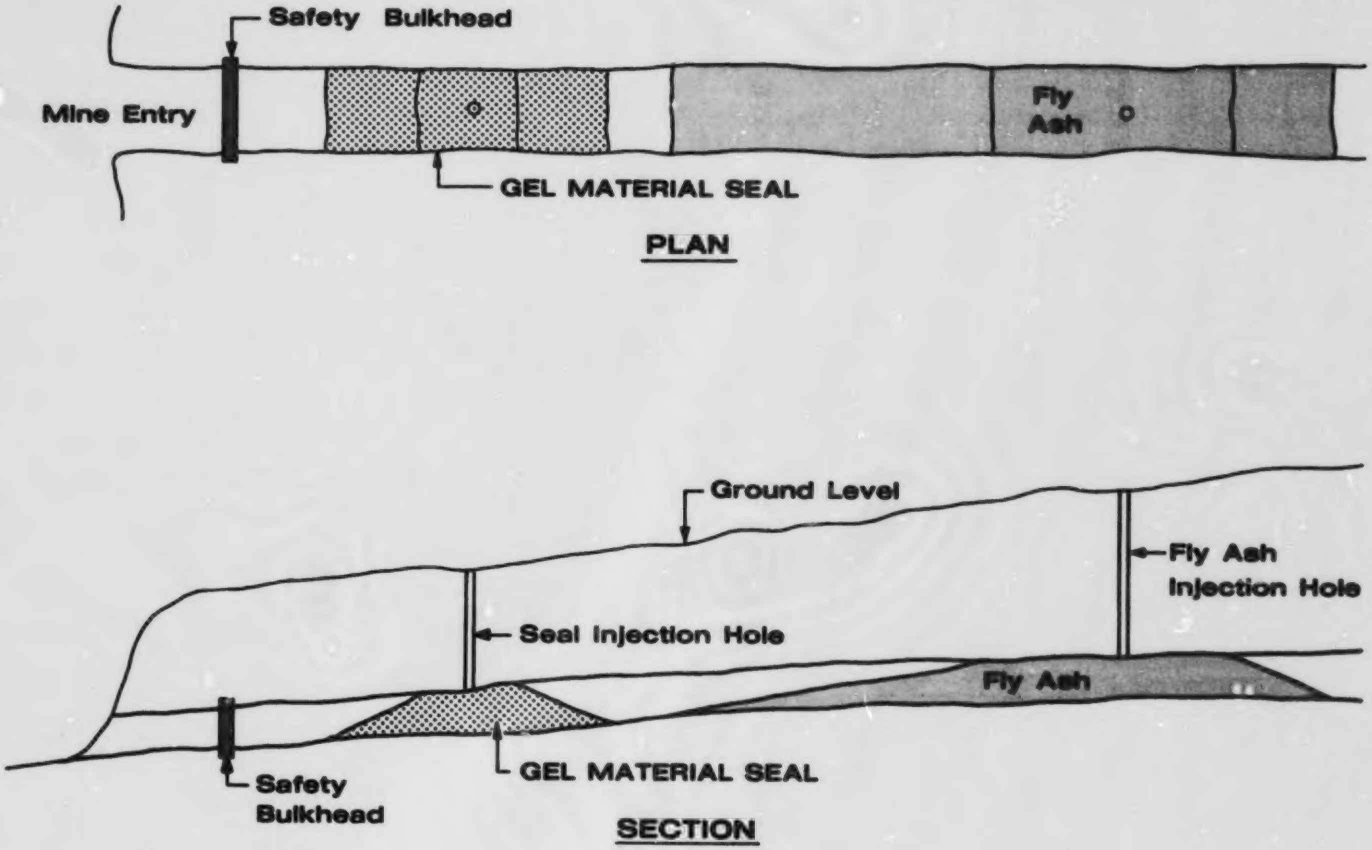

Safety Bulkhead
Mine Entry
Fly Ash
GEL MATERIAL SEAL
PLAN
Ground Level
Fly Ash Injection Hole
Seal Injection Hole
Fly Ash
Safety Bulkhead
GEL MATERIAL SEAL
SECTION

FIGURE 18. - Arrangement of proposed gel material seal.

- Masonry Block or Brick Seal - $1,300.00 to $1,500.00 average cost for construction of numerous seals in the Dressen Mine, also located near Terre Haute, Indiana. Average size of these seals was 1.5 m. (4.9 ft.) high x 4 m. (13.1 ft.) wide x 0.8 m. (2.6 ft.) depth.
- Grouted Aggregate Seal - $8,848.00 per seal for two seals in Mine No. 40-016 in West Virginia, through $2,083.90 for an undetermined number of seals in the Thomas Mills Mine area of Pennsylvania. Approximate opening dimensions were 2 m. (6.5 ft.) x 3.7 m. (12.1 ft.), with variable lengths extending into the mine passageway.
- Quick Setting Seal - $3,564.00 for a single seal constructed near Clarksburg, West Virginia. The 1.5 m. (4.9 ft.) x 3.7 m. (12.1 ft.) x approximately 2.7 m. (8.9 ft.) length seal was constructed in Mine No. 62-008, which mined the Pittsburgh Coal Seam.

Gunite Seal

An experimental and untested type of seal, known as the gunite seal, could be classified as a single bulkhead. Plans and specifications have been prepared for this high hydraulic head type seal, and technologically it should be found to be a viable method of mine sealing.

Gunite, a pneumatically-placed low slump concrete, is placed in continuously successive, nearly vertical layers in a mine opening until the opening is filled. This should prove to be a very rapid method of filling the void. However, the mine roof, floor and sides require shaping to allow the seal to withstand high hydraulic heads and a wooden bulkhead must be constructed on the mine site of the seal to allow an "anchor" for the gunite to build upon. This seal is limited to use in accessible mine openings of reasonably sound adjacent strata which will allow the required shaping. An expansive-type cement should, preferably, be used in making up the gunite. Figure 19 shows a plan and section of a gunite seal.

The approximate cost of the gunite seal, including curtain grouting of all sides, is expected to approach $13,000.00 per seal.

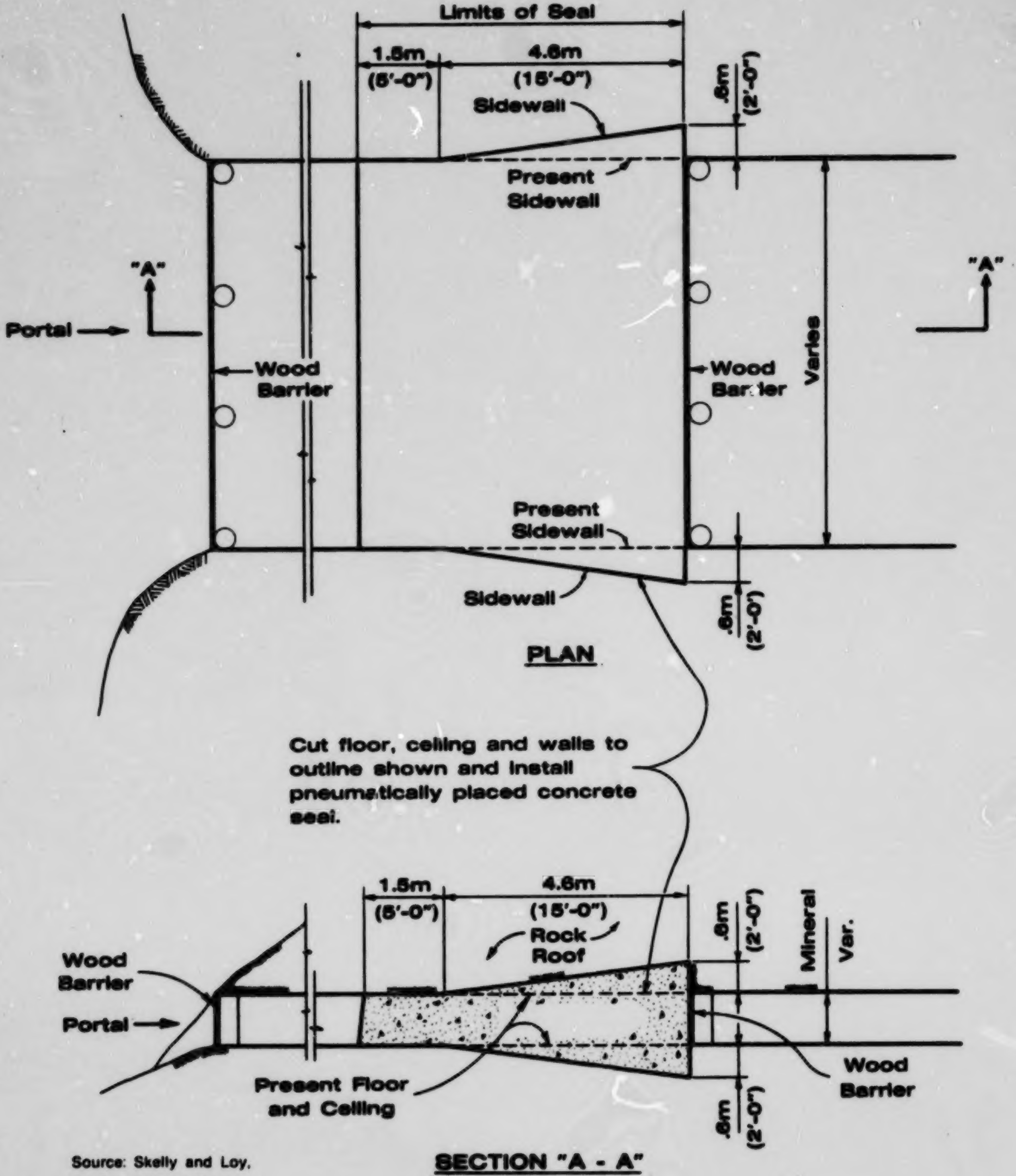
Clay Seal

Clay may be used to form an impermeable seal at the openings of underground mines under certain conditions. Accessibility to the opening for both manpower and equipment is necessary, since hand placement and compaction is recommended to ensure a firm anchor between the plug and the area surrounding the seal. Under ideal conditions a clay seal may withstand a hydraulic head of up to 9.1 m. (30 ft.) (Michael Baker, Jr., Inc. (b), 1973).

The quality of the clay should be as follows:

- The material to be used for the construction of the impervious plugs shall consist of more than 50% clay as defined by any nationally recognized Textural Classification Specifications, such as U.S. Department of Agriculture, American Association of State Highway Officials, U.S. Army Corps of Engineers, Civil Aeronautics Administration or U.S. Bureau of Public Roads. The upper limit of the particle size used to define the clay is 0.005 mm.
- The clay shall have a liquid limit greater than 50, with medium to high plasticity, and practically impervious drainage characteristics.

All loose material, or material of any kind that may be deleterious to the clay seal, should be removed from the seal area prior to construction.


Limits of Seal
1.5m
(5'-0")
4.6m
(15'-0")
Sidewall
.6m
(2'-0")
Present
Sidewall
"A"
"A"
Portal
Wood
Barrier
Wood
Barrier
Varies
Present
Sidewall
Sidewall
.6m
(2'-0")
PLAN
Cut floor, ceiling and walls to outline shown and install pneumatically placed concrete seal.
1.5m
(5'-0")
4.6m
(15'-0")
Rock
Roof
.6m
(2'-0")
Mineral
Var.
Wood
Barrier
Portal
Wood
Barrier
Present Floor
and Ceiling
.6m
(2'-0")
SECTION "A - A"

Source: Skelly and Loy,
Engineers-Consultants,
1973

FIGURE 19. - Gunite mine seal.

The clay is then placed in layers and compacted in such a manner that it will be forced into the cracks and voids in the perimeter of the seal area.

Earth backfill should then be placed and compacted over the seal area to prevent surface erosion of the clay plug due to climatic conditions, as well as giving the clay plug added capacity to withstand a hydraulic head. Revegetation should then be undertaken. Typical clay seals are illustrated in Figures 20 and 21.

Source: Skelly and Loy, Engineers-Consultants, 1973

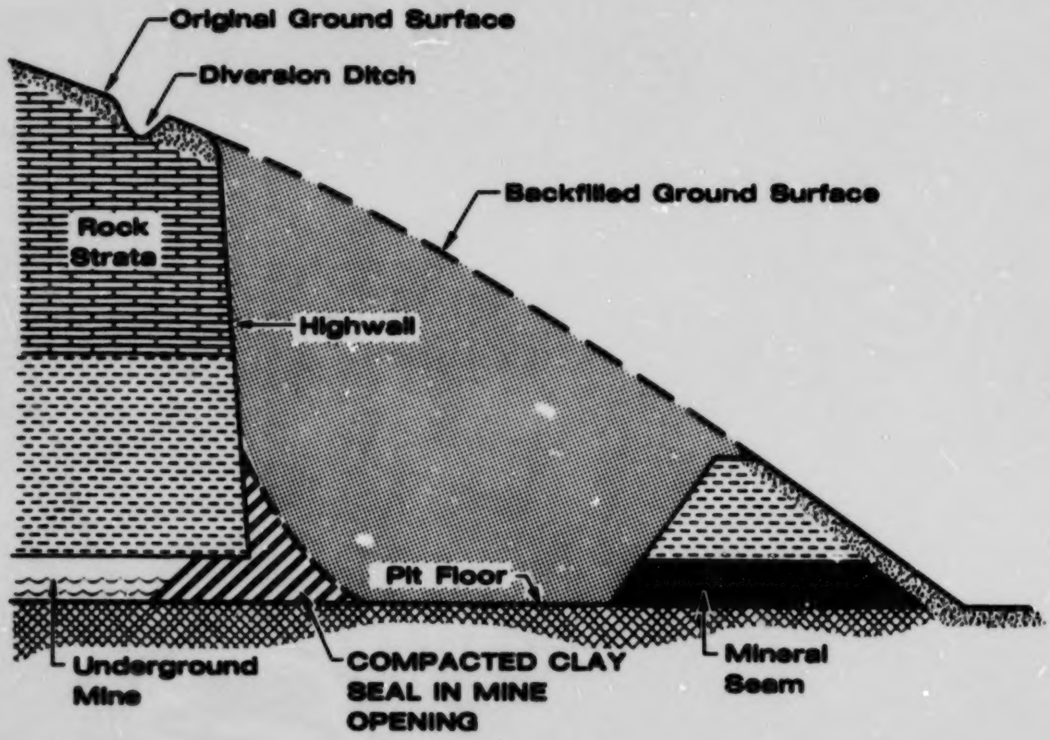
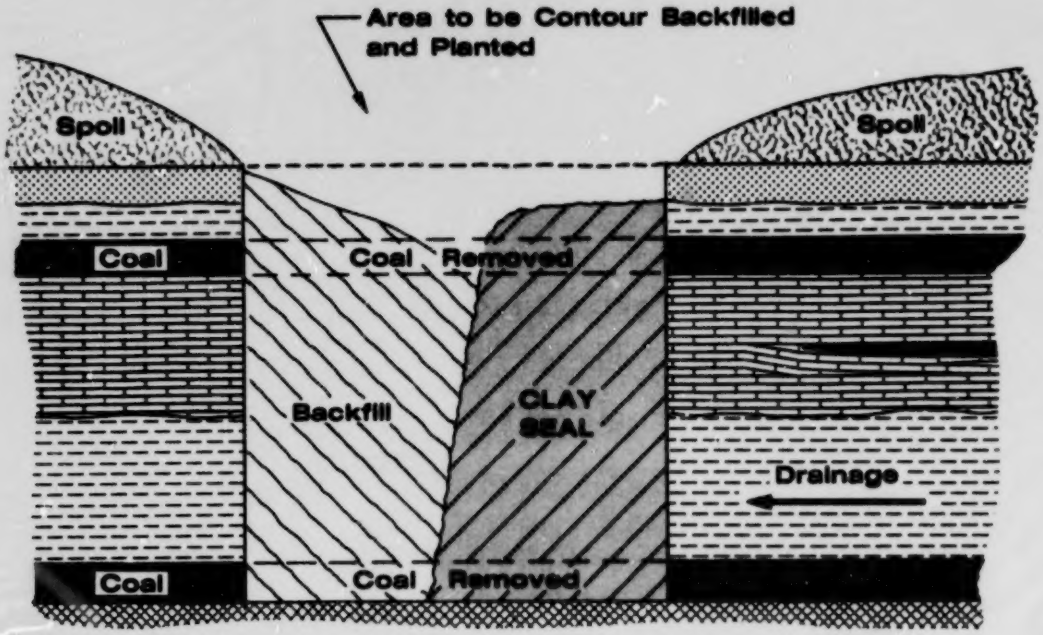

Original Ground Surface
Diversion Ditch
Backfilled Ground Surface
Rock Strata
Highwall
Pit Floor
Underground Mine
COMPACTED CLAY SEAL IN MINE OPENING
Mineral Seam

FIGURE 20. - Cross section of typical clay seal.

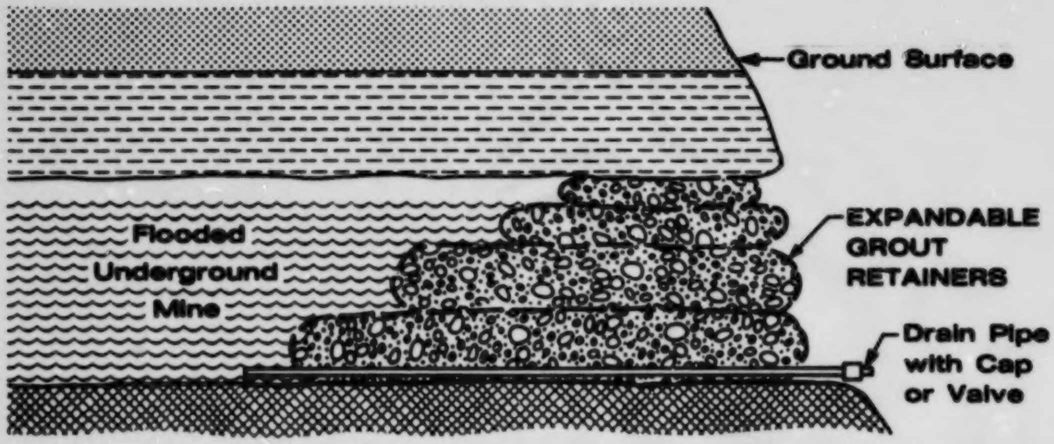

Area to be Contour Backfilled and Planted
Spoil
Spoil
Coal
Coal Removed
Backfill
CLAY SEAL
Drainage
Coal
Coal Removed

Adapted from Michael Baker, Jr., Inc. (b), 1975

FIGURE 21. - Excavated clay seal in shallow overburden.

Grout Bag Seal

The grout bag seal is an experimental idea developed for use in accessible mine entries. It's concept is to fill or inflate impermeable nylon retainers or bags with a free-flowing, fast setting cement. Each bag will be the same width as the mine opening but will vary in height and length depending on its stacked position. As the bags are filled they conform to the shape of the floor, walls and roof. Once a bag has filled and the cement has set sufficiently, another is placed on top and the process is repeated until the void is filled. The top lying bag is sometimes made of permeable cotton to promote a tighter seal with the mine roof. The spaces between and around each bag are also grouted to create a watertight seal. Some cleaning and reshaping of the mine entry are required with this seal and pressure grouting of fractured adjacent strata is highly recommended (Figure 22).



Adapted from Skelly and Loy, Engineers-Consultants, 1973

FIGURE 22. - Cross section of expandable grout retainer underground mine seal.

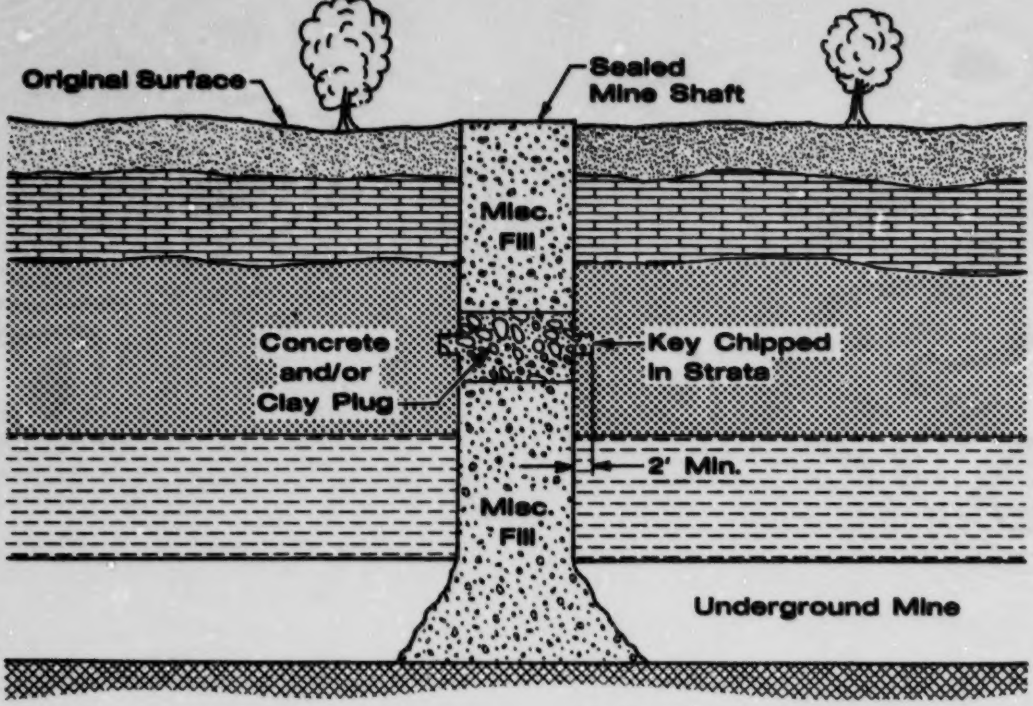
Updated cost estimates taken from figures published in the U.S. EPA's Report titled "Inactive and Abandoned Underground Mines — Water Pollution Prevention and Control" (1975) are shown below for installation of a grout bag seal. Assuming a standard of a 9.1 m. (30 ft.) expandable grout bag and four (4) bags to fill the entry, the expected construction costs are:

• Site Preparation	$ 675.00
• Entrance Preparation	425.00
• Four (4) Expendable Grout Retainers	1,620.00
• Piping, Valves, Labor	1,080.00
• Incidental Expenses	270.00
• Water Hauling and Storage	335.00
• Filling Material	3,800.00
• Mixing and Placement Equipment	960.00
Total Estimated Cost	$9,165.00

Shaft Seal

A shaft is a vertical, or near vertical, entrance-way into an underground mine, as opposed to a "drift," or horizontal mine entry. Shafts require sealing when one of two criteria relative to the underground mine is desired. One is the elimination of an air supply to the mine, and to a lesser degree the elimination of storm water runoff into the mine. The second criterion is the elimination of mine effluent discharges from the shaft. The water in the mine could be the result of a naturally high groundwater table, or a "perched" water table caused by sealed mine openings at lower elevations.

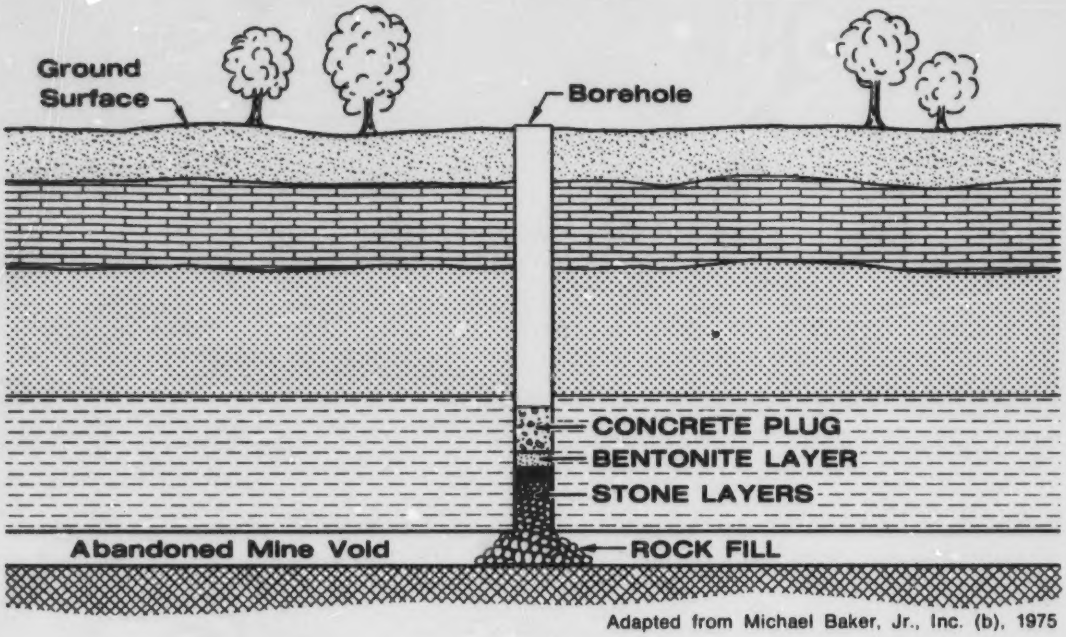
A hydraulic shaft seal generally is a completely filled shaft, which includes the choking off of the mine passageway, as shown in Figure 23. Costs involved in sealing a shaft by backfilling range from $7,000.00 for a 30.5 m. (100 ft.) depth shaft to $35,000.00 for shafts 152.4 m. (500 ft.) deep.


Original Surface
Sealed Mine Shaft
Misc. Fill
Concrete and/or Clay Plug
Key Chipped in Strata
2' Min.
Misc. Fill
Underground Mine

Adapted from Michael Baker, Jr., Inc. (b), 1975

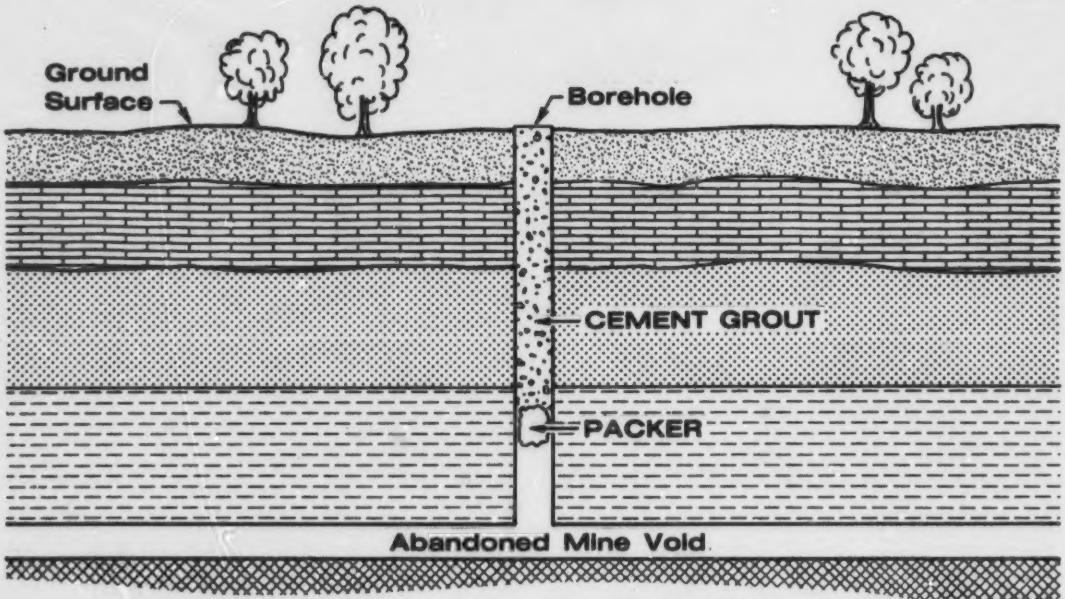
FIGURE 23. - Hydraulic shaft seal with keyed plug.

An approach similar to that used for shafts is also used for borehole sealing. During a comprehensive mine sealing program, in which all identified drifts, shafts, subsidence holes, stripped outcrops, etc., are sealed, it is easy to overlook a borehole/drillhole as small as 7.6 cm. (3 in.) in diameter, until increasing water pressure from inside the mine causes the hole to begin discharging. Remedial measures entail packing or keying into solid rock and backfilling or grouting the borehole to surface level. Construction methods used for sealing these smaller diameter holes (shafts) are illustrated in Figures 24 and 25.


Ground Surface
Borehole
CONCRETE PLUG
BENTONITE LAYER
STONE LAYERS
Abandoned Mine Void
ROCK FILL

Adapted from Michael Baker, Jr., Inc. (b), 1975

FIGURE 24. - Hydraulic borehole seal with bentonite and concrete.


Ground Surface
Borehole
CEMENT GROUT
PACKER
Abandoned Mine Void

Adapted from Michael Baker, Jr., Inc. (b), 1975

FIGURE 25. - Typical method of borehole sealing with cement grout.

Regulated Flow Seal

A regulated flow seal is a theoretical, although promising, method of discharging a predetermined amount of mine effluent to a given source.

Depending upon the thickness and permeability, or lack thereof, of the mine overburden, the "response time" (the time a mine takes to increase discharge after precipitation has occurred) of a mine discharge can be a matter of hours or extend to several weeks. Accordingly, if a mine has a long response time it is conceivable that a large acid discharge could be occurring at a period of exceptionally low surface stream flow. If the mine is discharging directly to a stream, decidedly adverse environmental effects could result.

However, if a mine has been hydraulically sealed, and a regulated flow valve installed in the lowest seal, the stream flow rate could be monitored and the mine effluent released according to the streams capacity to assimilate the pollutants in the mine discharge.

Another economically attractive use for a regulated flow valve in a hydraulic seal is that it allows the design of a treatment facility to incorporate a finite amount of inflow, thereby eliminating plant design for "peak flows" which invariably results in a large plant treating small average flows.

A third alternative would be a system of piping and valves that would allow the mine discharge to flow directly to a receiving stream during periods when the stream could assimilate it. However, the mine discharge would be diverted to a treatment plant during low stream flow periods.

This type of seal is proposed for use when the hydraulic head, which is developed in a mine due to complete sealing and inundation, becomes too high to be safely retained by hydraulic seals. A determination of the allowable mine pool depth would be made, relative to the maximum hydraulic heads the seals could withstand during the design year precipitation, and an emergency overflow borehole drilled through the strata surrounding the mine at that elevation (pool depth). The hydraulic seals are then designed to withstand this hydraulic head.

The type of seal used for the application can be any of the hydraulic seals discussed previously in this report.

The cost of this theoretical, technically feasible method of acid mine drainage abatement would necessarily be site specific. Total construction expense would depend on a comparison of the costs of seals required to hold a higher hydraulic head than would be necessary if a free flowing discharge were allowed, to the costs incurred in constructing a larger "peak flow" treatment plant.

When applied to a suitable location, this technique could result in a substantial savings in treatment plant capital costs and operating expenditures.

Permeable Limestone Seal

A permeable limestone seal is a hydraulic closure which acts as an acid mine drainage treatment structure. Permeable alkaline aggregate (limestone) is placed in the mine opening where water may pass through it. As the acidic water passes through the alkaline material, neutralization of the water occurs and a precipitate forms. The precipitate eventually fills the spaces in the aggregate, creating a solid single bulkhead seal. The mine would then become completely flooded.

The permeable limestone seal has been used only in demonstration projects by the U.S. EPA. Experience with several sites in West Virginia have shown that the closure is effective in improving water quality and reducing the volume of mine discharge. The neutralization of acid mine drainage is expected, however, to decrease as the limestone aggregate becomes coated with precipitate (Michael Baker, Jr., Inc. (b), 1973).

The total effectiveness of this multi-purpose closure method has not been fully evaluated because of the short time that most of the seals have been in sue, 5 to 10 years.

The costs of constructing limestone permeable seals will depend upon such factors as: size of the opening; materials; grouting requirements; site preparation; and proper selection utilization of equipment (Michael Baker, Jr., Inc. (b) 1973). Costs have ranged from $3,048 to $22,125 per seal.

TEMPORARY AND SEMI-PERMANENT CLOSURES

Numerous closures and safeguards have been developed for abandoned mine openings where safety and access control is the primary concern. Often, as in the case of metal mines, these safeguards are designed to allow future access to the mine at some future date for continued recovery of ore.

Mine opening safeguards used for this purpose are generally uncomplicated. Metal gates, wooden barriers and hinged covers over openings can be used as temporary or intermittent closures. Generally, these are applied to mines of low visitor interest and where stable soil or rock conditions allow construction. Because of their intended use for future access, they can easily be breached by the intentional trespasser. They should, however, deter the casual visitor.

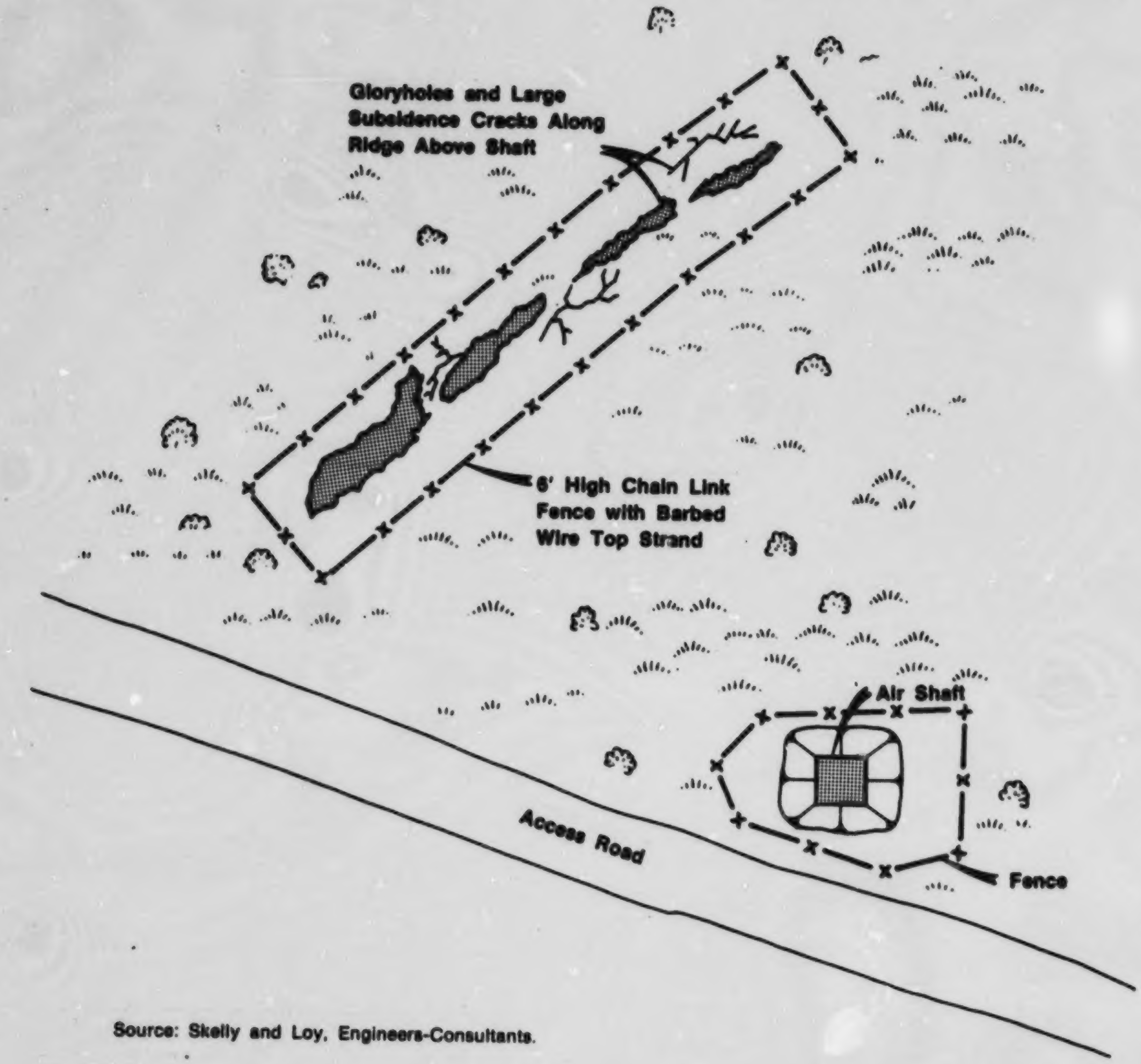
Fixed metal barricades, concrete slabs and heavy metal or wooden covers are more semi-permanent methods of closing openings. While they are easily removable by proper equipment, they discourage even the most determined trespasser and provide positive protection for the unaware visitor or hiker. These measures are most applicable to very hazardous openings and those with great temptation for unauthorized exploration.

In addition to the above safety seals, many of the air and dry seals are also applicable to provide semi-permanent mine closure for abandoned non-coal mine openings. These very effective closures include many variations of the air and dry seals discussed in preceding sections. Depending upon the extent of earthmoving, these closures can be removed with the proper equipment and investment for reentry. The most common method of safeguarding an opening is by the use of signs, fencing, access road closure or some other physical barrier to the mine. Generally, these measures are applicable only to openings with minor hazard. Safeguards such as these are often destroyed or stolen and in many cases, they serve to stop only the casual visitor allowing access to hikers and those determined to explore the opening.

The design of temporary and semi-permanent safety closures can take on many forms, depending upon such factors as the stability of the opening, the degree of hazard and accessibility for construction. For the three most generally applicable safeguards — fences, covers and gates — typical design illustrations are presented on Figures 26, 27 and 28.

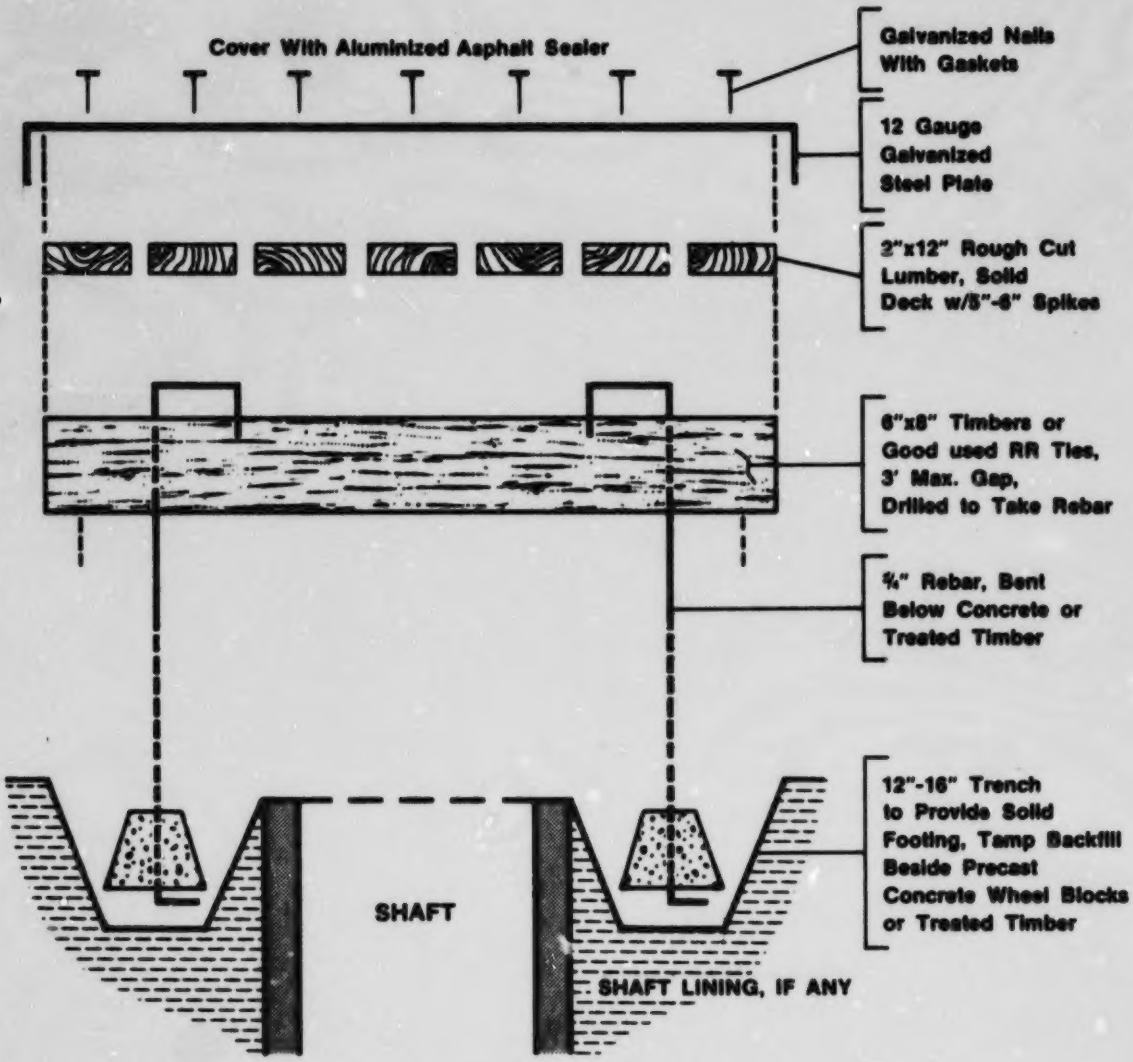
SELECTION AND USE OF CLOSURES

Prior to deciding which type of mine closure method could be used in a particular application, it is necessary to determine if a mine can be sealed or even if sealing is necessary. As previously discussed, many states do not require sealing of abandoned underground mines. Particularly in western non-coal mines, where mines are rarely abandoned or completely shut-down, the practice (and requirement) is usually the installation of fences, wooden barricades and occasionally uncompacted backfill. A seal in these types of mines is usually required only for health and safety protection and not for acid mine drainage abatement or subsidence control.


Gloryholes and Large Subsidence Cracks Along Ridge Above Shaft
6' High Chain Link Fence with Barbed Wire Top Strand
Air Shaft
Access Road
Fence

Source: Skelly and Loy, Engineers-Consultants.

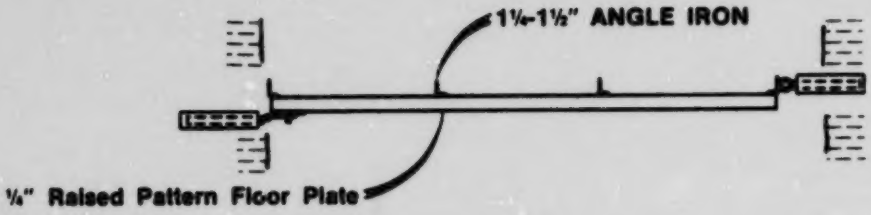
FIGURE 26. - Suggested fencing for open adit and glory holes.


Cover With Aluminized Asphalt Sealer
Galvanized Nails With Gaskets
12 Gauge Galvanized Steel Plate
2"x12" Rough Cut Lumber, Solid Deck w/5"-6" Spikes
6"x8" Timbers or Good used RR Ties, 3' Max. Gap, Drilled to Take Rebar
¾" Rebar, Bent Below Concrete or Treated Timber
12"-16" Trench to Provide Solid Footing, Tamp Backfill Beside Precast Concrete Wheel Blocks or Treated Timber
SHAFT
SHAFT LINING, IF ANY

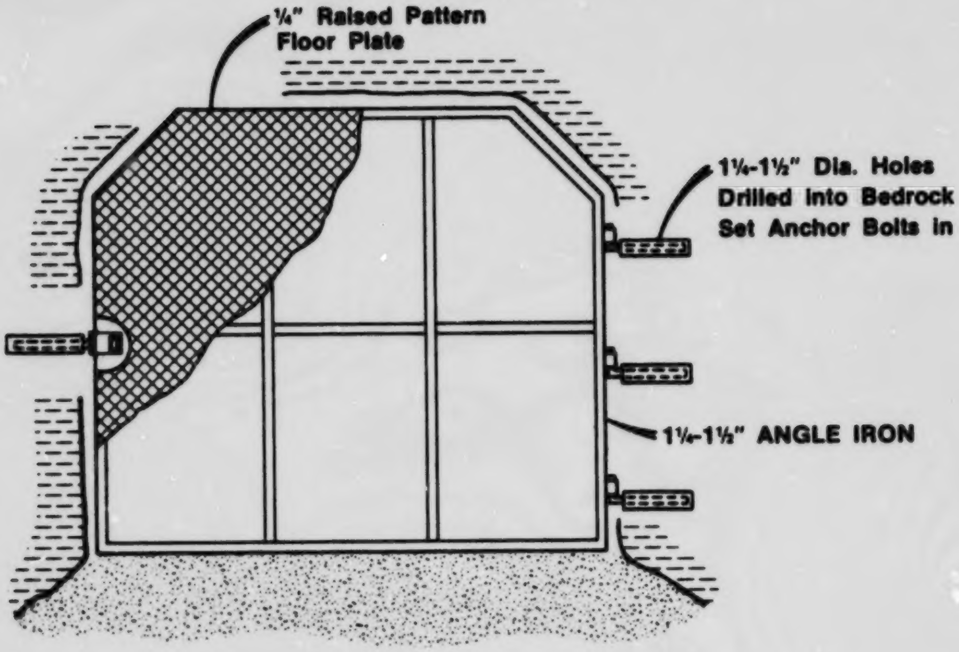
Note: Used railroad ties can be used for subgrade if in well-preserved condition; railroad ties and 6 in. timber can be used for spans up to 12-15 ft. In all cases surface drainage should be diverted away; concrete and/or railroad tie base is intended principally to discourage removal of cover by pulling with truck/winch.

Source: Skelly and Loy, Engineers-Consultants.

FIGURE 27. - Suggested cover for stable adit.


1¼-1½" ANGLE IRON
¼" Raised Pattern Floor Plate

PLAN


¼" Raised Pattern Floor Plate
1¼-1½" Dia. Holes Drilled Into Bedrock Set Anchor Bolts In
1¼-1½" ANGLE IRON

ELEVATION

Source: Skelly and Loy, Engineers-Consultants.

FIGURE 28. - Steel gate safeguard for stable adit.

If it is determined that a mine should be sealed, it may be found that sealing may not be possible. Any number of the following situations may prevent sealing:

- Too great a hydraulic head
- Fractured roof, side walls or pillars
- Weak structural integrity of strata surrounding mine entry
- Potential for gas build-up and fires
- Mining in adjacent area which could cause a change in hydrology

If it is found that a mine can be sealed, the intended purpose of the closure must be resolved before the sealing method can be selected. To do so, the following list of economic, engineering and geologic factors should be taken into consideration:

- Is a mine pool to be formed due to installation of the seal?
- Should the seal be watertight?
- Will the seal "pretreat" the mine drainage?
- Is the purpose of the seal intended solely to prevent mine entrance by people and animals?
- Is the area in which the seal is to be placed accessible?
- Are the strata in which the seal is to be placed strong enough to prevent roof falls? If not, an economic evaluation between a strong roof-supporting type seal and a more economical closure incorporating roof timbering must be made.
- Is the area in which the seal is to be placed an actively mined area?

- Is there future mining potential from the opening that dictates a temporary closure?
- How severe is the safety hazard for casual visitors?

Maintenance of seals has generally been limited to inspecting the structural condition of dry seals and air seals, as well as cleaning the water traps in air seals. Major problems with seal maintenance generally are associated with hydraulic seals, due to two factors which cause leakage. These factors are the pressures generated by the mine water impounded behind the seal, and the acidic nature of the impoundment. Presently, the generally accepted means of restoring a leaking hydraulic seal or its surrounding strata is to use a form of pressure injected grout. This has proven, in general, to be a partially effective means of resealing leaking seals; however, no better technology is presently available that is applicable to this task.

In designing mine closures it is necessary to address certain design criteria and to quantify particular data concerning the water quality, hydrology and geology of the surrounding environment. Among these are the following:

- The strata in which the seal is to be constructed must be evaluated for its ability to withstand the forces transmitted to it by the seal.
- The entire perimeter of the mine, its outcrops, subsidence areas, overlying and underlying strata in general, must be evaluated and shown to be of an integrity that will allow the mine pool to form, or of such a nature that grouting or some other form of reinforcing will bring it to that point.

- The pressure acting on the seal and the surrounding strata (walls, roof, pillars) due to the height of the water impounded behind it, if any must be determined. When inundating a mine to the maximum extent possible, the highest seasonal water table must be taken into account; however, if an air seal is intended for use, only the mine pool created by the seal need be considered. Where the anticipated head exceeds the capabilities of the seal, some type of mine pool draw down system must be included to prevent the head from exceeding real design limits.
- If an air seal is to be designed, the sediment load of the mine effluent should be determined, and the water trap designed accordingly.

The above factors point out some of the constraints preliminary questions that must be considered before a sealing program or closure design is carried out. To determine which mine closure method is most applicable to a particular problem, it is necessary to further address a series of geologic, engineering, economic and environmental criteria applicable to the conditions of the opening and types of closures available.

To add in this process, guides for the selection and use of mine closure methods are presented in Tables 6, 7 and 8. These guides provide a summation of the major factors which determine the applicability of the various dry, air, hydraulic and temporary/semi-permanent closure techniques. The use of these guides following appropriate site investigations will provide reasonable assurance as to the expected cost and effectiveness of the selected closure method.

TABLE 6. - Guide to selection

SEAL TYPE AVAILABLE		GEOLOGIC			
		② ACCEPTABLE HYDROLOGIC CONDITIONS	③ ROOF STABILITY	④ FLOOR CHARACTERISTICS	⑤ ACTIVE MINING RESTRICTIONS
DRY SEALS	Earth Fill	No water at seal location.	Applicable to fractured and stable conditions.	Clay or rock floor acceptable.	Resistant to seismic disturbances.
	Earth Fill and Rock	No water at seal location.	Applicable to fractured and stable conditions.	Clay or rock floor acceptable.	Resistant to seismic disturbances.
	"U.S. Bureau of Mines"	No water at seal location.	Requires roof timbering for fractured conditions.	Requires solid rock footing.	Susceptible to seismic disturbances.
	Vertical Shaft	No water pooling at or above elevation of seal.	N/A	N/A	Susceptible to seismic disturbances.
AIR SEALS	"U.S. Bureau of Mines"	Continuous infiltration or flow.	Requires roof timbering for fractured conditions.	Requires solid rock footing.	Susceptible to seismic disturbances.
	Earth Backfill	Continuous infiltration or flow.	Requires roof timbering for fractured conditions.	Requires solid rock footing.	Resistant to seismic disturbances.
	Clay and Rock Water Trap for Caved Pit Mouth	Continuous infiltration or flow.	Applicable to fractured/caved conditions.	Clay or rock floor acceptable.	Resistant to seismic disturbances.
	Trap	Continuous infiltration or flow.	Applicable to fractured conditions.	Requires solid rock footing.	Resistant to seismic disturbances.

① Parameters listed and discussed on this chart are considered variable between seal types. Parameters common to a hydraulic seal application, regardless of type, are discussed elsewhere.

② Dry seals must be protected from both mine effluent and storm water runoff.

③ "Weak" seals, those not capable of supporting a roof fall, require timbering.

④ Seals with thin sections, and resultant small perimeter area to act as seal support, require floor excavation to solid strata.

⑤ Seismic disturbances relates to vibrations caused by mine blasting.

of air and dry seals.①

ENGINEERING					
⑥ RANGE OF HYDROSTATIC HEAD	PROTECTIVE COATING AGAINST ACID MINE DRAINAGE REQUIRED ⑦	⑧ HITCHES REQUIRED	SPECIAL EQUIPMENT REQUIRED	⑨ MAINTENANCE REQUIRED UNDER STABLE CONDITIONS	CONSTRUCTION MATERIALS USED
None	No	No	Hand compaction equipment.	None	Native earth.
None	No	No	Hand compaction equipment and earthmoving equipment.	None	Selected rock and native earth.
None	No	Yes	"Foam" application equipment.	None	Concrete and concrete block, filled with fly ash and faced with urethane foam.
None	No	No	None	None	Concrete, reinforcement.
Controlled by design of trap barrier and discharge pipe, maximum head limited to seam height.	Yes	Yes	—	None	Concrete and concrete block, filled with fly ash and faced with urethane foam, piping.
Theoretically effective to 3.0 m (3,023 kg/m^2), 10' (4.3 psi).	Yes	Yes	Hand compaction equipment.	Yearly rodding of discharge pipe.	Timbering, concrete, solid concrete block, native earth, piping.
Controlled by design of discharge pipe; however, generally limited to no hydrostatic head.	No	No	Drilling equipment.	Monthly cleaning of trap.	Plastic clay (upper limit of particle size = 0.005 mm), random rock, concrete, selected rock to form culvert.
Controlled by design of trap barrier and discharge pipe, effective head limited only by surrounding strata.	Yes	Yes	None	Monthly cleaning of trap.	Concrete, reinforcement, piping.

⑥ Values shown are either based on case histories or theoretical values.

⑦ Exposed concrete, brick, or block is especially vulnerable to AMD corrosion.

⑧ Hitches are generally required for thin section seals.

⑨ "Stable Conditions" means no violent seismic activity, roof falls that create solution channels, or badly deteriorating rib conditions due to AMD deterioration.

TABLE 6. - Guide to selection

SEAL TYPE AVAILABLE		ENGINEERING	ECONOMICS		
		ENGINEERING AND DESIGN NEEDS UNIQUE TO SEAL TYPE	⑩ CONSTRUCTION COST (Case History Average Updated to 1979 Cost)	MAINTENANCE COST UNDER STABLE CONDITIONS	⑪ LIFE EXPECTANCY UNDER STABLE CONDITIONS
DRY SEALS	Earth Fill	None	$2,500.00	Yearly inspection @ $250.00.	Permanent
	Earth Fill and Rock	Design thickness of selected rock wall.	$2,500.00	Yearly inspection @ $250.00.	Permanent
	"U.S. Bureau of Mines"	None	$1,300.00 to $1,500.00	Yearly inspection @ $250.00.	Permanent
	Vertical Shaft	None	—	Yearly inspection @ $250.00.	Permanent
AIR SEALS	"U.S. Bureau of Mines"	Recommended for use in openings which discharge heavily silt-laden effluent.	$4,000.00 to $5,000.00	Yearly inspection @ $250.00.	If AMD present, protective coating will eventually deteriorate, allowing concrete blocks to be dissolved. Time frame is dependent on AMD strength.
	Earth Backfill	Recommended for use where moderate hydrostatic head is required.	$4,000.00	Yearly inspection @ $250.00 plus yearly cleaning of pipe @ $250.00.	AMD problems relative to concrete block same as above; however, earth backfill will maintain seal effectiveness indefinitely due to impermeability formed while concrete block is effective.
	Clay and Rock Water Trap for Caved Pit Mouth	Recommended for use where roof is fractured to such a degree that induced caving is used.	$2,500.00 to $4,500.00	Yearly inspection @ $250.00 plus monthly trap cleaning @ $125.00 per month.	Rock permeability will allow mine discharge to immediately begin forming a flow net through the clay backfill. Therefore, life expectancy is somewhat shorter than an Earth Backfill Seal.
	Trap	Recommended for use where high hydrostatic heads are required in addition to controlled effluent discharge.	$3,200.00	Yearly inspection @ $250.00 plus monthly trap cleaning @ $125.00 per month.	Thickness of solid, reinforced concrete virtually assures permanent seal.

⑩ Costs are a function of the size of the opening being sealed, as well as the nature of the water handling system.

⑪ Case Histories have indicated that the surrounding strata deteriorates in a matter of a few years, relative to the strength of the acid effluent, thereby rendering the seal ineffective, although intact. In the case of non-coal mines, effectiveness has been "permanent" for those cases where data is available.

of air and dry seals - (Cont'd.)

ENVIRONMENTAL					
SURFACE RUNOFF STORM WATER HANDLING	ACID MINE DRAINAGE ABATEMENT CAPABILITY ⑫		⑬ CONSTRUCTION SAFETY	DOWNSTREAM SURFACE INHABITANT SAFETY- IN EVENT OF CATACLYSMIC FAILURE	HISTORY OF USE
	GREAT	LITTLE			
Requires construction of stormwater diversion ditches or dikes, plus face plantings to prevent erosion.	No	Yes	Requires minimal work in mine mouth - somewhat less risk than normal underground factor.	No risk	Most common use where AMD or effluent discharge is not a factor. However, outby face of seal requires protection from surface runoff.
Same as Earth Fill.	No	Yes	Same as Earth Fill.	No risk	A variation of the earth fill seal. No real advantage over the earth fill type. Used during the U.S. Bureau of Mines 1930's sealing program.
Protected from direct stormwater detrimental effects.	No	Yes	Requires work a minimal distance "in by" from mine mouth - same risk as normal underground factor.	No risk	Used where opening conditions are especially stable, and material availability is evident. Reopening capability is superior to the types listed above.
Earth backfill should be formed in a manner that will divert stormwater runoff.	No	Yes	Vertical Shaft Sealing is a high risk item.	No risk	Used to "cap" shafts when backfilling is impractical.
Protected from direct stormwater detrimental effects.	No	Yes	Requires work a minimal distance "in by" from mine mouth - same risk as normal underground factor.	Little risk of flooding due to small hydrostatic head contained, and virtually no chance of pipe blockage.	"Triple Wall" construction allows maintenance free air seal as relates to sediment accumulation. Used during the U.S. Bureau of Mines 1960's sealing program.
Face of earth backfill must be protected as in Earth Seals, if strength of total seal is to be maintained.	Yes	—	Same as "U.S. Bureau of Mines."	Moderate hydrostatic head and possibility of pipe blockage equates to moderate risk of flooding.	Used under conditions that require moderate hydrostatic head control. Long discharge pipe somewhat complicates maintenance of silt free operation.
Same as Earth Backfill.	No	Yes	Preparatory work required to form blind ditch in hazardous opening is very high risk.	Construction of seal is such that the "pipe" could readily clog, thereby producing a moderate risk of flooding.	Used during U.S. Bureau of Mines 1930's sealing project. Requires little or no materials other than native rock and clay. Trap very easy to maintain.
Protected from direct stormwater detrimental effects.	Yes	—	Same as "U.S. Bureau of Mines."	Elevated mouth of discharge pipe makes clogging unlikely; however, high hydrostatic heads can develop behind seal in the event of clogging, thereby producing a great risk of flooding.	Used where positive design for high hydrostatic heads is desired. Possible to create mine pool by limiting discharge from mine.

⑫ Acid Mine Drainage Abatement Capability is related to a seals capacity to retain and/or discharge mine effluent in a controlled manner.

⑬ Construction Safety is directly proportional to the expenditures allocated to shoring/stabilizing the work area, as it relates to accessible seal construction sites.

TABLE 7. - Guide to selection

SEAL TYPE AVAILABLE	GEOLOGIC		
	② ACCEPTABLE HYDROLOGIC CONDITIONS	③ ROOF STABILITY	④ FLOOR CHARACTERISTIC
Double Bulkhead	Continuous infiltration or flow in steeply pitching mine.	Applicable to fractured and stable conditions.	Clay or rock floor acceptable.
Single Bulkhead: Poured Concrete	Continuous infiltration or flow in steeply pitching mine.	Applicable to fractured and stable conditions.	Requires solid rock footing.
Masonry Block or Brick	Continuous infiltration or flow in flat seams.	Requires roof timbering for fractured conditions.	Requires solid rock footing.
Grouted Aggregate	Continuous infiltration or flow in moderately pitching seams.	Applicable to fractured and stable conditions.	Clay or rock floor acceptable.
Quick Setting Gel Material	Continuous infiltration or flow in moderately pitching seams.	Applicable to fractured and stable conditions.	Clay or rock floor acceptable.
Gunite	Continuous infiltration or flow in steeply pitching mine.	Applicable to fractured and stable conditions.	Requires solid rock footing.
Clay	Continuous infiltration or flow in steeply pitching mine.	N/A	N/A
Grout Bag	Continuous infiltration or flow in moderately pitching seam.	Applicable to fractured and stable conditions.	Clay or rock floor acceptable.
Vertical Shaft	Continuous infiltration or flow in any seam.	N/A	N/A
Special Seals: Regulated Flow	Continuous infiltration or flow in any seam.	Dependent on type of material chosen for construction.	Dependent on type of material chosen for construction.
Permeable Limestone	Continuous infiltration or flow in flat or moderately pitching seams.	Applicable to fractured and stable conditions.	Clay or rock floor acceptable.

① Parameters listed and discussed on this chart are considered variable between seal types. Parameters common to a hydraulic seal application, regardless of type, are discussed elsewhere.

② Pitch of seam being mined determines seal type, due to hydrostatic head imposed on seal.

③ "Weak" seals, those not capable of supporting a roof fall, require timbering.

④ Seals with thin sections, and resultant small perimeter area to act as seal support, require floor excavation to solid strata.

of hydraulic seals.①

ENGINEERING			
⑤ CONSTRUCTION SITE ACCESSIBILITY	⑥ ACCESS HEIGHT	⑦ ACTIVE MINING RESTRICTIONS	⑧ RESTRICTIVE PERMEABILITY CONDITIONS AT SEAL POSITION
Can be remotely installed.	Unrestrictive.	Resistant to seismic disturbances.	Unrestricted use inherent in length flexibility.
Seal position must be accessible.	Minimum 2' working height required.	Resistant to seismic disturbances.	Unrestricted use inherent in length flexibility.
Seal position must be accessible.	Minimum 2' working height required.	Susceptible to seismic damages.	Usually restricted to low permeability areas.
Can be remotely installed.	Unrestrictive.	Susceptible to seismic damages.	Unrestricted use inherent in length flexibility.
Can be remotely installed.	Unrestrictive.	Resistant to seismic disturbances.	Usually restricted to low permeability areas.
Seal position must be accessible.	Minimum 2' working height required.	Resistant to seismic disturbances.	Usually restricted to low permeability areas.
Seal position must be accessible.	Unrestrictive.	Resistant to seismic disturbances.	Usually restricted to low permeability areas.
Seal position must be accessible.	Minimum 2' working height required.	Susceptible to seismic damages.	Usually restricted to low permeability areas.
Seal position must be accessible.	Unrestrictive.	Susceptible to seismic damages.	N/A
Seal position must be accessible.	Minimum 2' working height required.	Dependent on type of material chosen for construction.	Dependent on type of material chosen for construction.
Can be remotely installed.	Unrestrictive.	Resistant to seismic disturbances.	Unrestricted use inherent in length flexibility.

⑤ Seals designated as capable of being remotely installed can also be installed on site.

⑥ "Unrestrictive" access height assumes remote installation.

⑦ Seismic disturbances relates to vibrations caused by mine blasting.

⑧ A determination must be effected as to the permeability of the strata in the seal area, at the expected hydrostatic head pressure, and the seal effective perimeter area designed accordingly.

TABLE 7. - Guide to selection

SEAL TYPE AVAILABLE	ENGINEERING		
	⑨ RANGE OF HYDROSTATIC HEAD	⑩ PROTECTIVE COATING AGAINST ACID MINE DRAINAGE REQUIRED	⑪ HITCHES REQUIRED
Double Bulkhead	Effective to between 30' and 40' (13.0 to 17.3 psi) (9.14m to 12.19m) (9,140 kg/m^2 to 12,163 kg/m^2)	No	No
Single Bulkhead: **Poured Concrete**	Historically, effectiveness limited only by surrounding strata.	Yes	Yes
Masonry Block or Brick	Effective to between 3' and 5' (1.3 to 2.2 psi) (0.91m to 1.52m) (914 kg/m^2 to 1,547 kg/m^2)	Yes	Yes
Grouted Aggregate	Effective to 10' (4.3 psi) (3.0m) (3,023 kg/m^2)	No	No
Quick Setting Gel Material	Theoretically effective to 10' (4.3 psi) (3.0m) (3,023 kg/m^2)	No	No
Gunite	Theoretically effective to 35' (15.2 psi) (10.67m) (10,687 kg/m^2)	No	Yes Specially shaped floor, ribs, and roof.
Clay	Effective to 30' (13.0 psi) (9.14m) (9,140kg/m^2)	No	No
Grout Bag	Effective to 10' (4.3 psi) (3.0m) (9,023kg/m^2)	No	No
Vertical Shaft	Historically, effectiveness limited only by surrounding strata.	Yes	Yes
Special Seals: **Regulated Flow**	Dependent on type of material chosen for construction.	Dependent on type of material chosen for construction.	Dependent on type of material chosen for construction.
Permeable Limestone	Head controlled by permeability of limestone seal; however, ultimate head should be effective to 10' (4.3 psi) (3.0m) (3,023 kg/m^2).	No	No

⑨ The values presented are those established by field trials, or theoretically calculated for a "typical" installation.

⑩ Exposed concrete, brick, or block is especially vulnerable to AMD corrosion.

⑪ Hitches are generally required for thin section seals.

of hydraulic seals - (Cont'd.)

ENGINEERING			
⑫ SPECIAL EQUIPMENT REQUIRED	⑬ MAINTENANCE REQUIRED UNDER STABLE CONDITIONS	CONSTRUCTION MATERIALS USED OR DESIGNED TO BE USED	ENGINEERING AND DESIGN NEEDS UNIQUE TO SEAL TYPE
Pressure grouting equipment - drilling equipment.	None	Retaining bulkheads — grouted coarse aggregate, quick setting cement or chemical slurry. Center seal — concrete, grout, light cement.	Surface survey to locate subsurface entryway for remote installation - boring probes to pinpoint seal location - optical equipment to observe entryway.
None	None	Concrete, reinforcing bars, bituminous or "foam" type protective coating.	None
None	None	Concrete, mortar, cement block, brick, bituminous or "foam" type protective coating, timbering.	None
Pressure grouting equipment - drilling equipment.	Remedial grouting at seal-entry interface.	Grouted coarse aggregate.	Surface survey to locate subsurface entryway for remote installation - boring probes to pinpoint seal location - optical equipment to observe entryway.
Pressure application equipment - drilling equipment.	Remedial grouting at seal-entry interface.	Controlled setting time chemical grout or gel, historically a vinyl polymer grout, combined with a "filler" of, usually, fly ash.	Surface survey to locate subsurface entryway for remote installation - boring probes to pinpoint seal location - optical equipment to observe entryway.
Pneumatic placement equipment.	None	Gunite (low slump concrete), wooden bulkhead.	None
Hand compaction equipment and earth-moving equipment.	None	Plastic clay (upper limit of particle size = 0.005mm), earth backfill.	None
Pressure grouting equipment.	Remedial grouting at seal-entry interface.	Nylon or cotton cloth grout retainers, grout slurry (cement).	None
None	None	Concrete, reinforcing bars, bituminous or "foam" type protective coating.	None
Dependent on type of material chosen for construction.	Dependent on type of material chosen for construction.	Choose construction material to be compatible with entryway to be sealed. Pipe and valving as necessary to pass desired flow rates.	None
Drilling equipment.	None	3/8" (0.95cm) to dust sized acid neutralizing limestone aggregate.	Surface survey to locate subsurface entryway for remote installation - boring probes to pinpoint seal location - optical equipment to observe entryway.

⑫ Equipment listed assumes remote installation of applicable seals.

⑬ "Stable Conditions" means no violent seismic activity, roof falls that create solution channels, or badly deteriorating rib conditions due to AMD deterioration.

TABLE 7. - Guide to selection

SEAL TYPE AVAILABLE	ECONOMICS			THEORETICAL BENEFICIAL EFFECT ON SURFACE SUBSIDENCE PREVENTION ⑯	
	⑭ APPROXIMATE ESTIMATED CONSTRUCTION COST	MAINTENANCE COST UNDER STABLE CONDITIONS	⑮ LIFE EXPECTANCY UNDER STABLE CONDITIONS	GREAT	LITTLE
Double Bulkhead	$12,500.00 to $25,000.00	Yearly inspection @ $250.00.	Permanent	Yes	—
Single Bulkhead: Poured Concrete	$3,200.00	Yearly inspection @ $250.00.	Permanent	Yes	—
Masonry Block or Brick	$1,300.00 to $1,500.00	Yearly inspection @ $250.00.	Susceptible to acid attack if used in highly pyritic coal seams, therefore life span limited.	No	Yes
Grouted Aggregate	$2,100.00 to $8,800.00	Drilling 7.5 cm (3") holes $10.66 LM ($3.25 LF) cement for grouting $110.25 metric ton - $100.00 ton.	Generally accepted as a permanent seal.	No	Yes
Quick Setting Gel Material	$3,600.00	Same as Grouted Aggregate Seal.	Inconclusively field tested. No life expectancy projected.	No	Yes
Gunite	$22,000.00	Yearly inspection @ $250.00.	Not field tested as yet; however, it is expected that this seal will be permanent.	Yes	—
Clay	$1,000.00	Yearly inspection @ $250.00.	Field tests to date have not demonstrated effectiveness of seal. No life expectancy projected.	Yes	—
Grout Bag	$9,200.00	Same as Grouted Aggregate Seal.	Failure of grout bags to maintain tight perimeter with opening renders this seal ineffective in a short time.	No	Yes
Vertical Shaft	$20,000.00 to $25,000.00	Yearly inspection @ $250.00.	Permanent	Yes	—
Special Seals: Regulated Flow	Dependent on type of material chosen for construction. Piping cost = $200.00±.	Dependent on type of material chosen for construction.	Dependent on type of material chosen for construction.	Dependent on type of material chosen for construction.	
Permeable Limestone	$5,000.00 to $10,000.00	Yearly inspection @ $250.00.	Theoretically permanent	Increases with exposure to acid mine drainage.	

⑭ Costs are a function of the size of the opening being sealed, as well as a function of the seal design, i.e., hydrostatic head contained, anchoring conditions.

⑮ Case Histories have indicated that the surrounding strata deteriorates in a matter of a few years, relative to the strength of the acid effluent, thereby rendering the seal ineffective, although intact. In the case of non-coal mines, effectiveness has been "permanent" for those cases where data is available.

⑯ Beneficial Effects on surface subsidence prevention is related directly to the seal's hydrostatic head capability, and the resultant mine pool formed.

of hydraulic seals - (Cont'd.)

ENVIRONMENTAL				
ACID MINE ⑰ DRAINAGE ABATEMENT CAPABILITY		⑱ CONSTRUCTION SAFETY	DOWNSTREAM SURFACE INHABITANT SAFETY- IN EVENT OF CATACLYSMIC FAILURE	HISTORY OF USE
GREAT	LITTLE			
Yes	—	Normally remotely installed from surface - generally safe.	Risk of flooding great, due to high hydrostatic head capability.	Developed for sealing inaccessible mine openings. Used extensively at Moraine State Park.
Yes	—	If seal installed in entryway back from mouth of mine, normal underground risk factor.	Same as Double Bulkhead.	First type of seal used. Used most often in non-coal mines for high hydrostatic head retention.
No	Yes	Same as Poured Concrete.	Little risk of flooding, due to small hydrostatic head contained.	Early type of seal. Use sometimes combined with poured concrete, with block acting as formwork.
No	Yes	Seal generally installed by pneumatic means near entrance, or remotely from surface - generally safe.	Same as Masonry Block or Brick.	Generally used as a remote installation where moderate to low hydrostatic heads are expected.
No	Yes	Developed to be remotely installed - generally safe.	Same as Masonry Block or Brick.	Use limited to experimental application to date. Generally unsuccessful.
Yes	—	Same as Poured Concrete.	Same as Double Bulkhead.	An experimental seal so far untested in the field. However, similarly shaped concrete seals have been effective against very high hydrostatic heads.
Yes	—	Seal installed at mine mouth - minimum risk.	Same as Double Bulkhead; however, earth backfill would possibly limit flow.	Generally used as a method of sealing multiple openings, with the use of heavy equipment. However, applicability to single seals is evident.
No	Yes	Same as Clay Seal.	Same as Masonry Block or Brick.	Use limited to experimental application to date. Limited success.
Yes	—	Installation of concrete cap within shaft equates to same risk factor as underground work.	No risk.	Proven application - used extensively over a long period of time.
Dependent on type of material chosen for construction.		Can be expected to be constructed in mine mouth - minimum risk.	No risk.	An experimental application of sealing/water handling. Untested to date.
Theoretically stable throughout life of seal.		Seal generally installed near mine mouth or remotely installed - generally safe.	Risk increases as seal approaches complete impermeability; however, total risk small.	Use limited to experimental application to date. Treatment aspects of seal successful; however, precipitate chocking less than desired.

⑰ Acid Mine Drainage Abatement Capability is also related to hydrostatic head capabilities, and the resultant mine pool formed.

⑱ Construction Safety is directly proportional to the expenditures allocated to shoring/stabilizing the work area, as it relates to accessible seal construction sites.

TABLE 8. - Guide to selection of temporary

SEAL TYPE AVAILABLE	TYPE OF MINE OPENING BEST SUITED TO SEAL TYPE	GEOLOGIC	
		ACCEPTABLE HYDROLOGIC CONDITIONS	STABILITY IN IMMEDIATE AREA OF OPENING
Earth Backfill	Shafts, inclines	No drainage at seal location.	Immaterial
Heavy Wood and Steel Covers	Shafts, steep inclines	No drainage at seal location.	Must be capable of accepting anchors.
Fencing	Shafts, glory holes	Drainage into or out of mine acceptable.	Immaterial
Steel Gates	Adits	No drainage at seal location.	Must be capable of accepting drill holes for anchors.
Wooden Barricades	Adits	Drainage into or out of mine acceptable.	Immaterial
Pushed Earth/ Rubble Backfill, With Pulled Support To Induce Caving	Adits	No drainage at seal location.	Immaterial
Blasting for Multi-Opening Highwall	Adits	No drainage at seal location.	Immaterial
Surface Regrading	Glory holes	Surface drainage diverted from glory hole.	Immaterial
Earth Backfill with Pipe	Adits	Effluent from mine piped to desired discharge point.	Must be stable in area of pipe inlet, to prevent caving and subsequent pipe blockage.

① Parameters listed and discussed on this chart are considered variable between seal types. Parameters common to a hydraulic seal application, regardless of type, are discussed elsewhere.

and semi-permanent seals.①

ENGINEERING				
ACTIVE MINING RESTRICTIONS ②	SPECIAL EQUIPMENT REQUIRED	MAINTENANCE REQUIRED UNDER STABLE CONDITIONS ③	CONSTRUCTION MATERIALS USED	ENGINEERING AND DESIGN NEEDS UNIQUE TO SEAL TYPE
None	Earthmoving equipment - dozers, load-haul-dump equip.	None	Common earth and/or graded, selected earth/stone backfill.	Backfill placed in mine opening must be at optimum moisture content.
Susceptible to seismic disturbances.	None	Yearly inspection.	12 gauge galvanized steel plates, 2" x 12" rough cut lumber, 6" x 8" timbers (or R.R. ties) and cement anchors.	Cap must be designed to allow desired holding capacity across span of opening.
None	None	Yearly inspection.	Fencing material acceptable to authorizing state agency.	None
Susceptible to seismic disturbances.	Rock drills, welding equipment.	Yearly inspection.	⅜" to ½" expanded metal plate decking.	Steel fabrication drawings must be prepared.
None	None	Yearly inspection.	Barricades constructed in a manner acceptable to the authorizing state agency.	None
None	"Gradall" type of earthmoving equipment.	None	Spoil piles, abandoned buildings, structures, etc., pushed into openings, covered with caved highwall.	Soil study must be made to allow accurate estimate of caved material quantity.
None	Rock drills, blasting equipment, "Gradall" type of earthmoving equipment.	None	Common caved earth and rock.	Blasting plan must be prepared.
None	Earthmoving equipment.	None	Earth backfill and topsoil.	None
Some chance of pipe rupture due to seismic action.	Earthmoving equipment.	Yearly rodding of discharge pipe.	Concrete pipe, common caved earth and rock.	Blasting plan must be prepared.

② Seismic disturbances relate to vibrations caused by mine blasting.

③ "Stable Conditions" means no violent seismic activity, roof falls that create solution channels, or badly deteriorating rib conditions due to AMD deterioration.

TABLE 8. - Guide to selection of temporary

SEAL TYPE AVAILABLE	ECONOMICS		
	CONSTRUCTION COST	MAINTENANCE COST UNDER STABLE CONDITIONS	LIFE EXPECTANCY UNDER STABLE CONDITIONS
Earth Backfill	Dependent upon volume of backfill and equipment used.	Yearly inspection @ $250.00.	Permanent
Heavy Wood and Steel Covers	Estimated cost for constructed railroad tie on concrete footing over shaft = $1,600.00.	Yearly inspection @ $250.00.	Permanent
Fencing	Estimated cost for installed 6' chain link with barbed wire fencing 260' in length = $4,400.00.	Yearly inspection @ $250.00.	Dependent on material chosen for construction.
Steel Gates	Estimated cost for installed 80 square ft. steel gate = $1,800.00.	Yearly inspection @ $250.00.	Permanent
Wooden Barricades	Estimated cost of 80 square ft. 2" x 12" plank barrier = $400.00.	Yearly inspection @ $250.00.	Dependent on material chosen for construction.
Pushed Earth/ Rubble Backfill, With Pulled Support To Induce Caving	Dependent upon volume of material and equipment used.	Yearly inspection @ $250.00.	Permanent
Blasting for Multi-Opening Highwall	Dependent upon required loading for adequate fragmentation and length of highwall.	Yearly inspection @ $250.00.	Permanent
Surface Regrading	Dependent upon volume of material and equipment used.	Yearly inspection @ $250.00.	Permanent
Earth Backfill with Pipe	Dependent upon volume of material and equipment used.	Yearly inspection @ $250.00 plus yearly rodding of pipe @ $250.00.	Permanent

and semi-permanent seals - (Cont'd.)

ENVIRONMENTAL		
SURFACE RUNOFF STORM WATER HANDLING	CONSTRUCTION SAFETY	HISTORY OF USE
Must be protected from erosion, especially at interface of fill and existing ground.	No unusual safety hazards. Normal heavy equipment operation.	A "semi-permanent" type of seal. Used primarily where shafts or inclines are being abandoned, within a working mine.
Must be diverted around seal.	Work in area of vertical shaft very hazardous - increased safety awareness required.	Used where shafts or inclines are likely to be reopened. Not normally used in coal mines. Secure against trespass.
No effect.	No unusual risk factors.	Used where willful trespassing or illegal entry into mine is unlikely. Can be easily reopened. Use unlikely in coal mines.
No effect.	Requires work a minimal distance "in by" from mine mouth - same risk as normal underground factor.	More secure than fencing against trespass, but can be reopened. Use unlikely in coal mines.
No effect.	No unusual risk factors.	Generally interchangeable with fencing, if allowed by state law.
Must be protected from erosion.	Requires work a minimal distance "in by" from mine mouth - same risk as normal underground factor.	Same as Earth Backfill.
Must be protected from erosion.	Safety operations controlled by blasting plan.	Same as Earth Backfill.
Divert surface runoff to bypass seal area.	Nature of "Glory Holes" very hazardous. Stability of area surrounding "Glory Hole" must be evaluated.	Used as a corrective measure where underground mine subsidence has caused surface depressions. Not a "seal" unless surface opening is evident.
Must be protected from erosion.	Requires work a minimal distance "in by" from mine mouth - same risk as normal underground factor.	Same as Earth Backfill.

SUPPLEMENTARY AND ALTERNATIVE CONTROLS

Discussed within this section is available supplementary and alternative technology for facilitating closure effectiveness. The contribution of these techniques, either for prevention or abatement of mine drainage has in most cases not been firmly quantified, although practice has frequently shown them to be effective. Nevertheless, the theory for their utility, especially in problem mines that are considered "un-sealable" by existing methods, makes them worthy of consideration. The combined uses of these methods along with the previously discussed closure technology may, if properly applied, provide the most cost-effective solution to mine closure problems.

SLURRY TRENCHES AND ALKALINE REGRADING

A slurry trench is a narrow trench of varying depth excavated vertically into unconsolidated spoil material, which has been backfilled against a highwall. The trench is excavated to a predetermined depth below the working level of the mine in an attempt to anchor the base of the trench in impervious material. Ideally, the excavated material is then combined with a clay slurry and placed in the trench to ground level. If the excavated material is unsuitable for combination with clay slurry, a material must be chosen that will be compatible with the backfilled soil. As the slurry evaporates or percolates away, the slurry becomes an impermeable clay like, forming a "groundwater dam". This dam then causes the water that would normally discharge to back up and inundate the mine.

Slurry trenches are being used or are planned for controlling drainage discharges from underground mine openings, outcrop areas, highwalls, or surface strip mines that have intersected underground workings. In all of these instances, the purpose of the slurry trench is to raise the water level in the mine to a predetermined elevation, inundate the oxidizable sulfur minerals, and thereby reduce or eliminate the formation of acid. The mine pool is then allowed to discharge over the top of the slurry wall.

Alkaline regrading is an acid mine drainage abatement technique that has been developed to be especially applicable to situations where surface mining has been conducted adjacent to the underground mine entries and where there is an alkaline rock present in the overburden of the coal seam being mined.

Upon completion of mining operations, the alkaline spoil material is backfilled against the highwall and the mine entries, regraded to a modified contour, terrace, or some other backfill configuration. The percolation rate of the underground mine drainage through the completed backfill will be relatively slow, and consequently, the contact time between any acid waters and the neutralizing alkaline materials will be maximized. It has been proposed that slurry trenches be placed in the regraded alkaline backfill at the furtherest point possible from the face of the highwall, thereby achieving the benefits of both the slurry trench (inundation of at least some of the mine workings) and alkaline regrading, since water over topping the slurry "dam" will have an even greater contact and reaction time with alkaline material in the spoil.

DISCHARGE TREATMENT

Acid mine drainage results from the oxidation of organic (coal) or inorganic (metallic) sulfides producing soluble and acid-forming sulfate salts. As the earlier discussions of mine closure regulation indicated, both mine effluents and the downstream water quality attributable to those effluents are strictly regulated at both federal and state levels (effluent limitations and stream quality standards). In cases where other forms of closure (sealing, etc.) do not appear feasible due to projected hydraulic heads or excessive potential for leakage, or where an "air seal" as described earlier would be used, any discharge from the mine workings at the time of closure must be dealt with. In such cases, the required mine effluent concentration levels can be achieved through a combination of chemical and physical processes. Mine drainage treatment using lime or limestone neutralization, electrodialyses, reverse osmosis, ion exchange, freezing and iron oxidation, among others, have been attempted and have met with varying degrees of success in recent years. The mechanisms involved for each of these methods is discussed below.

Lime/Limestone Neutralization

To counteract the effect of acid-producing sulfate ions, an alkaline material must be added to the mine water. The most common alkali additives are lime and limestone. Lime, as quick lime or hydrated lime, is more completely and quickly dissolved and thereby is the most effective acid-neutralizing alkali. The powered and/or liquified state of the lime allows more surface area for dissolution and faster reaction time with acidic mine discharge.

Lime reacts with the acidic constituents of mine drainage to form calcium sulphate, a soluble salt, and ferric hydroxide or "yellow-boy", a stable iron compound that precipitates from solution as pH increases or hydrogen ion activity decreases.

Limestone neutralization is similar to lime treatment in that the end products of the reaction are soluble salts and precipitated stable compounds, with associated decreases in free sulphate ions and hydrogen ion activity. Any dissimilarity occurs in the efficiency and speed of reaction. Limestone takes much more time to dissolve and react, even when crushed, since it is already in a stable form.

Reverse Osmosis

Reverse osmosis, although highly effective in removing dissolved solids from acid mine drainage, is not widely used as a method of treatment sine it has virtually no effect on pH levels. Water is filtered through one of three types of membranes, the spiral wound, tubular or hollow fiber. The membranes are designed to allow water or solvent to pass through the fiber filters while remaining impermeable to the dissolved solids or solute. Once the filters are full of collected distillates it cannot continue to pass solvent. At that time the membrane must be back flushed and the resulting solute or brine must be properly stored in settling ponds. Further treatment of this brine is a problem due to the extreme ion concentrations. Aside from extensive neutralization of these concentrates, some suggested handling techniques have included; evaporation, deep well injection, coagulation, further filtration and neutrolosis process. Each of these methods have been described and evaluated (Skelly and Loy, 1973.)

Electrodialysis

Electrodialysis is a tried but unproven method of acid mine drainage treatment. Similar to the reverse osmosis membrane, this unit processes mine water through membranes, ultimately separating the drainage into an acceptable, clear discharge and a concentrated dissolved, solids brine. The electrodialysis unit differs from the previously described reverse osmosis tubes in that each compartment contains two membranes, a cation and anion, and a positive and negative electrode at opposite ends of the unit. When the unit is energized, the membranes attract their respective ions and concentrate them into pockets of brine water while allowing the distilled feed water to pass through. Again, as in the case of the reverse osmosis process, more than 85% of the dissolved solids are removed from the original mine water, but the pH, acidity, iron and manganese (due to their fouling affect on the membranes) remain below Environmental Protection Agency acceptance levels.

Data on the costs of mine drainage treatment by electrodialysis is insufficient and outdated at present since no practical testing of this unit has been attempted for more than a decade.

Ion Exchange

Ion exchange is a technique of water quality upgrading which is based on the extraction and concentration of ions from solution by reaction with a solid medium, containing monovalent ions, which by themselves are insoluble when released. The reversible exchange takes place as mine water is flushed through channels containing crystal networks of weakly bonded ions. Replacement of these single-charged ions with stronger bonding ones from solution, without destroying the original crystal latice or disturbing the required electrical balance, is the theory behind the operation of the ion exchange unit. Recent improvement advances have been made in the design of the unit, most notably in the development of plastic resins to replace the original crystalline structure, ion exchange medium. These resins now contain a variety of latices or ionizable (weakly charged) groups which, in turn, have increased the output volumes and effectiveness of softening, demineralizing or specific ion removal from an aqueous solution.

The effectiveness of this process has been limited to minimizing concentrations of dissolved minerals rather than the elimination of acidity.

Freezing

Freezing is a method of treating wastewater which has been used in the purification of brackish water; however, very little experience has been gained in treating acid mine drainage by this method. In this process the wastewater is frozen and mineral-free fresh water ice crystals are formed; the dissolved minerals remain in solution and become concentrated; the ice is washed and melted and fresh water is produced. A study conducted by Applied Science Laboratories, Inc. (1971) analyzed various components of the freezing technique and concluded that reductions of more than 85% of the various metal and acid components were noted with little or no oxidation of ferrous iron. Because of the lack of experience in treating AMD by freezing, insufficient information exists to evaluate the effectiveness of this process and determine the costs.

Iron Oxidation

Iron pollution of streams can be as serious a problem as acidity. Iron compounds are present in minerals which sometimes lie adjacent to mined minerals, namely pyrites or iron sulfides. When these iron sulfides are exposed to air and moisture, they oxidize into an iron salt such as ferrous sulfate.

Iron in mine drainage is first detected in the ferrous form. This form of iron is very soluble in water but can precipitate as a hydroxide as the water's alkalinity concentration rises.

There are many methods in which ferrous iron can be oxidized into ferric iron so that the precipitate (unsoluble hydroxide) can be formed and then removed from the drainage water. Aeration, electrochemical oxidation and ozone oxidation are the most common of these.

It has been found that if oxygen is intermixed with the drainage water, the oxidation process can proceed much more rapidly. Installation of either diffused or mechanical equipment is the easiest method to accomplish intermixing.

Following chemical and physical principles, oxidation of ferrous iron to the ferric form can also be achieved through electrochemical reactions. This method of oxidation has been tested by Tyco Laboratories, Inc. (Skelly and Loy, 1973) using acid conditions that are found under normal field conditions. The conclusions drawn were that using electrochemical means to oxidize ferrous iron into the ferric form was successful and economically feasible.

A study conducted at the Brookhaven National Laboratory (Skelly and Loy, 1973) dealt with the use of ozone to oxidize ferrous iron into the ferric form. The conclusion of this study was that through the use of ozone (electrically produced), ferrous iron can be oxidized into the ferric form. Final neutralization of the acidity present in the mine drainage will be accomplished through the use of a limestone additive.

Evaporation Ponds

Evaporation ponds are utilized, where climatically feasible to impound the total amount of effluent discharging from an active or closed underground mine. The collected waste water is allowed to evaporate, thus preventing contamination of surface waters which would otherwise receive the discharge. The feasibility of this system is limited to areas which experience long periods of low rainfall occurance, and which could be classified as arid or semiarid in nature.

In design, an evaporation pond must accommodate not only the peak discharge expected from the mining facility itself, but also any other possible sources of water inflow, such as overland storm water runoff. Therefore, effective use of existing topography and diversion ditches must be made when siting the pond to eliminate extraneous sources of inflow.

When holding water in a pond for extensive periods of time, percolation through the soil and possible contamination of the groundwater in the area of the pond could result. It is, therefore, necessary to line the pond with an impervious material such as clay, vinyl or rubber. It is also important to anticipate and design for possible overtopping of the dike around the pond. An overflow structure, protected with a riprap or other suitable lining, will prevent the possible erosion of the dike if overtopping does occur during an extended wet weather period.

The effectiveness of evaporation pond has not thoroughly been documented for solo as a means of pollution prevention. Ponds, as presently utilized, allow the settling of insoluble compounds either before, or subsequent to, chemical treatment, or regulate the rate of discharge to treatment plants or receiving waters.

Controlled Release Reservoirs

Controlled release reservoirs are somewhat analogous to regulated flow deep mine seals, in that they are used to regulate mine effluent discharge quantities in response to stream flow rates (and subsequent stream dilution capabilities) in such a manner as to maintain acceptable water quality. The construction characteristics detailed for evaporation ponds generally also apply to controlled release reservoirs, except the reservoirs are sized on the basis of effluent flow rather than influent flow. With these reserviors, the receiving stream flow must be constantly monitored and the reservoir discharge adjusted accordingly to maintain proper dilution rates that will enable compliance with stream quality standards.

Such reservoirs have in the past seen application in more acid climates where mine infiltration and subsequent discharge levels are fairly low (one example was a surface/underground copper/sulfur mine complex in California), but they are not widely used because of the unpredictability of climatic conditions. In higher rainfall situations such as the east, the discharge volumes that would have to be impounded and later released are too great, and often exceed the neutralizing or diluting capabilities of the adjacent streams.

Underground Precipitation

Underground precipitation can occur in two forms. In its first form, an alkaline slurry is continuously pumped into acid mine drainage producing mine voids. The mine water, upon contact with the alkaline slurry, is neutralized, and a sludge is formed. This sludge will, ideally fill the mine void and prevent further acid drainage formation. Secondly, a rubble pile, consisting of rock, shale, etc., of sufficient particle size to form a barrier strong enough to withstand the anticipated hydraulic head, is placed in the mine opening. An alkaline slurry is then pumped behind the rubble pile, and upon coming into contact with the acid drainage, a sludge is produced which is carried into the voids in the rubble pile and eventually seals it. This is technically feasible in that the sludge produced is a "bulking" type, and will expand to a volume greater than that occupied by the individual, unreacted acid drainage and alkaline slurry. Either method has the advantage of disposing of sludge in-site, eliminating the sludge handling problems inherent in treatment plant facilities and, in effect, utilizing the mine itself as a "treatment plant."

INFILTRATION CONTROLS

Infiltration controls are designed to reduce the amount of water entering underground mines, and subsequently reducing the amount of drainage exiting the mine. These techniques can often be advantageously employed by active miners to decrease the volume of water that needs to be handled and treated.

Use of these infiltration controls for abandoned mine water pollution control is based on the premise that a decrease in the amount of flow exiting the mine will result in a decrease in the total pollution load. The pollution load is the actual weight of specific pollutants passing a point within a specified time period. The load is calculated by multiplying pollution concentration in the water by the amount of flow, using appropriate conversion factors. Loads are commonly expressed in the unit kilograms per day (pounds per day).

In order for controls to be useful in pollution reduction, the resultant decrease in flow must not be accompanied by a proportionate increase in pollution concentration. If such a trade-off should occur, the pollution load could remain essentially the same. This trade-off is not an entirely unlikely possibility.

Decreased flow from the mine as a result of infiltration controls may result in decreased water pollution if the amount of drainage is reduced sufficiently to prevent pollution transportation from the mine. In this case, because of hydraulic connection, the decrease in water pollution coming out to the surface could result in increases in groundwater pollution.

The techniques discussed in the following sections can be used to decrease the amount of water flowing through underground mines. Choice of technique and extent of its use will depend on hydrologic conditions in the area and cost effectiveness of the technique. These techniques are not universally applicable. Some mines are already receiving minimal infiltration, and further decreases may be difficult to obtain.

It should be noted that while infiltration generally occurs as a result of rainfall recharge to the groundwater reservoir, water can also enter from below, or laterally through the mineral or adjacent rock units. Rock fracture zones and faults have strong influence on groundwater flow patterns in that they often collect and convey large quantities of water.

Increasing Surface Runoff

Water infiltration can be decreased by increasing surface water runoff. This technique involves elimination of depressions which often collect and convey large quantities of surface water to underground mines. The amount of water collected depends on size of drainage area tributary to the depression, and annual rainfall and runoff rate.

Surface runoff can be increased by grading an overlying area to a smoother, better draining configuration. Surface depressions can be filled in and even lined with clay. Stream channels can be flumed, reconstructed with impermeable liners, or diverted around water loss areas. Channel stability under increased flows must be assured.

This technique is effective where water is lost in a stream channel. Large volumes of water can often be prevented from entering underground mines at relatively low cost. The capacity of a flume or reconstructed channel will have to be large enough to handle heavy rainfalls. Local hydrologic data detailing maximum runoff volumes for any storm over the normal frequency ranges is usually available.

Regrading Surface Mines

Surface mines are often responsible for collecting and conveying large quantities of surface water to adjacent or underlying underground mines. Non-regraded surface mines often collect water in an open pit where no surface exit point is available. Many abandoned underground mine outcrop areas have been contour stripped. These surface mines often intercepted underground mine workings, providing a direct hydrologic connection. The surface mine does not have to intercept underground mine workings in order to increase infiltration. Surface mines on the updip side of underground mines collect water and allow it to enter a permeable coal seam. It then flows along the coal seam to underground mines. Overlying surface mines that collect and entrap water can also be significant sources of infiltration. These surface mines facilitate entry of surface runoff to the groundwater system, which eventually works its way into an underground mine.

A regrading operation is then designed to conduct flow around a surface mine by diversion (and by flumes if necessary), and to increase surface runoff. Contour regrading may be preferred in this instance, because of its good drainage characteristics.

Surface mine regrading to prevent infiltration of surface water to underground mines is presently underway in the Dents Run Watershed, West Virginia. Reduction in underground mine flow has already been reported. The effectiveness of this technique for pollution abatement will depend on the amount of water being entrapped by the surface mine and the effectiveness of the reclamation work.

Sealing Boreholes and Fracture Zones

Boreholes and fracture zones act as water conduits to underground mines. They are usually vertical, or near vertical, and tap overlying aquifers.

Boreholes are commonly present around underground mines, remaining from earlier mineral exploration efforts. Boreholes can be easily sealed with hydraulically inserted concrete from below in an active underground mine. However, because abandoned holes are difficult to locate on the surface, and often blocked by debris, they can be difficult to seal from the surface.

Fracture zones are often major conduits of water, increasing vertical movement of water and causing large lateral movements. Fracture zones are usually vertically oriented planar type features which can be plotted by experienced personnel using aerial photography. Permeability of these zones can be reduced by drilling and hydraulic grouting. There are various types of grout available; however, concrete is commonly used.

Borehole seals should be located well above the roof of a mine to guard against roof collapse from additional water pressure. Fracture zone sealing in underground mines is theoretically possible, but documentation of successful applications was not found.

Interception of Aquifers

This technique takes advantage of the natural geologic and hydrologic systems surrounding a mined area. It involves use of boreholes, casing, and pumps to transfer water from one point to another in order to reduce water flow into an underground mine. The techniques are theoretical and will require development and demonstration to establish feasibility.

A complete hydrogeologic site evaluation of a mined area to determine aquifer characteristics and water flow systems is required prior to implementation. Most underground mines receive water from overlying aquifers. Several techniques can be employed to tap these aquifers and reduce the amount of water entering a mine. Overlying aquifers can be drilled and the water pumped to the surface, or boreholes can be drilled through aquifers, passing through an underground mine and into underlying aquifers. The borehole must be cased through the mined zone (it collects water from the overlying aquifer, passes it through the mine zone for discharge to an underlying aquifer). The underlying aquifer must be capable of accepting the anticipated flow.

A variation on this technique is to drill holes to the underground mine, case the last zone from the deep mine opening up into the roof. The boreholes are then connected by pipes and the water carried outside the mine. The uncased portion of the borehole collects water from overlying aquifers and passes it into the piping system for conveyance out of the mine, never contacting pollution forming materials.

Boreholes, pumps and piping systems can also be used to convey acid mine drainage to a nearby alkaline aquifer, or alkaline underground mine, to encourage mixing, neutralization and settling of precipitates.

Use of these systems is highly technical. Therefore, a groundwater geologist should be consulted to perform site evaluation, determine feasibility, and design the system.

These techniques are not universally applicable and will work only under favorable circumstances. System design will be variable, depending on local hydrogeologic factors.

SUBSIDENCE CONTROL

The unpredictable amount and rate of subsidence above mined out ore bodies and coal seams has prompted recent research to develop both mining technologies and post-mining remedial approaches to controlling surface deformation and reduce infiltration into the mine. As previously discussed, maximum extraction (non-supportive) mining methods such as longwall, shortwall and caving are designed for complete and immediate roof collapse with subsequent subsidence. Since the mine operator is obligated to purchase the surface rights for this type of mining, subsidence is planned for and, after initial ground settling, it is no longer a problem. Water circulation patterns are also easily reestablished as a result of complete subsidence over an area. Methods of reducing imminent subsidence damage from support mining operations (i.e., room and pillar mining) have recently leaned toward underground stabilization techniques of roof and rib supports. Some of the more successful approaches to stabilization include mine flushing or backfilling, grouting, pier construction, over excavation and backfilling and blasting. Each method is dependent upon the condition of the material to be supported and the extent of support needed, whether areal or localized.

To provide stabilization to weak overburden, methods of direct (controlled flushing) or remote (pressure flushing) backfilling has commonly been utilized. These methods transport crushed waste material, hydraulically as a slurry or pneumatically, and deposit it into the mine void as pier and bulkhead supports.

One unique method of remote flushing is the Dowell Process. It is an hydraulic filling method using high velocity water pressure to inject material into the mine through a single borehole. In application, this process requires large amounts of water and suitable (non-corrosive, non-cohesive) backfill material. The Dowell Process differs from other flushing methods in that it uses a "closed pumping" system, which works equally as well in flooded or unflooded mine situations. Since high water velocity is utilized to transport the support material, this technique works well for efficiently distributing support backfill throughout the mine.

Since only a portion of most waste rock from mines can be recycled as backfill, added expense is incurred by flushing techniques when importing extraneous material. Mines with unacceptable (highly acidic) or insufficient amounts of waste rock make up the majority of backfilled mines using imported materials. However, mines with high acid-producing potential or extremely inaccessible workings have also necessitated the use of specialized backfill materials which are foreign to the mine site. Fly ash, limestone chips, and lime-treated spoil, to name a few, have been used in acid mines, especially in situations of uncontrollable or expected mine seepage. For inaccessible workings, sand, which is more free-flowing than crushed waste, has been used.

A recently investigated alternative to underground stabilization against subsidence has been daylighting or overexcavating and backfilling. Daylighting eliminates subsidence by completely stripping out the deep mine and instituting a typical backfill and compaction plan such as those used in strip mining. The excess costs incurred by overburden removal can be minimized by any minable reserves left in the abandoned mine. Since stripping the entire overlying strata (as in mountaintop removal techniques) is very costly, situations for employing the daylighting technique should be limited to those abandoned mines with abundant known pillar and barrier reserves.

Localized or smaller scale subsidence prevention measures are most commonly related to areas of weak roof within a particular mine. Techniques including grout columns, in-mine piers, grout casings and constructed deep foundations have all been utilized in various combinations and situations. The construction of grout columns requires injecting pillars or bulkheads of a cement/mortar slurry into the mine opening, which with time, strengthens to form an incompressible pillar for support of a locally weakened roof. Similarly, grout casings are cement supports extending from the mine floor to a few feet into the roof. The object here again is to support small scale roof weakness or small groups of structures above weak roof conditions.

The construction of deep foundations is accomplished by drilling and grouting support holes which extend from stable, well-consolidated strata above the mine, down through weak roof, void and mine floor to capable, subjacent strata. These foundations are most feasible for shallow mines (30.5 m (100 ft.)) where pressures are less extreme. Conversely, piers or pillars within the mine are subject to the accessibility of an entry, but not the depth. The degree of deterioration of the roof at the time of installation, however, is an intense safety concern. Similar to timbering of active mines, pier construction is the shoring-up of the mine roof with concrete bulkheads and to a lesser degree, masonry and/or timbers. This method, although a possible safety hazard to workers when installing in older abandoned mines, is used commonly and has been effective for surface support. However, the effectiveness of pier construction, as with the other localized or small scale stability techniques mentioned above, is limited in that it protects a surface area much smaller in size than that area supported within the mine.

Preplanned or Controlled Mining

Planned mining procedures in the coal industry, such as longwall, shortwall and retreat mining or pillar robbing, create a situation of controlled drainage and complete subsidence due to the amounts of coal (approximately 90% of in-place reserves) extracted and the positioning of the remaining barriers. Areal surface subsidence then occurs in flat, trough-like depressions with maximum vertical displacement no greater than the original seam thickness. This type of controlled mining allows for an "instantaneous subsiding of undermined strata thereby greatly reducing future episodes of unexpected surface settling and reestablishing a solid, usable surface.

Additional benefits of complete roof collapse are realized when the size of the mine void is diminished by caving necessitating shallower mine pool levels to achieve inundation of acid-producing minerals.

Aside from mine development, acid mine drainage can be controlled by utilizing thicker outcrop barriers, grouting fractured overburden and disconformable (permeable contact) bedding planes limiting portal width under areas of unstable roofs and lining fractured or badly jointed barriers and/or overburden with impermeable (clay) blankets. Another planning consideration — mandatory downdip mine development — promotes mine inundation and subsequent acid load reduction. However, fractures, joints or very permeable strata directly above, below or in the coal barriers can negate the effect of gravity impoundment by dewatering the mine pool to a level below inundation of the oxidizing materials. Also, the quality of mine drainage can, by this procedure, worsen through the saturation and oxidation of permeable, pyrite and iron-bearing sandstones, which in some areas directly overlie minable coal reserves. Pre-mining exploratory boring and analyses of coal and overburden material and their relative condition will help determine remedial measures necessary to avoid this problem.

Besides pre-mining considerations, there are two lesser developed abatement techniques, mine backfilling and controlled atmosphere mining. Backfilling (hydraulic flushing) after mining is a stabilization practice most common to the anthracite coal regions of Pennsylvania. Direct or remote backfilling consists of the placement of sand, crushed spoil and/or fly ash into the void, either mechanically or pneumatically. This shores up fractured strata enough to decrease the amount and subsidence and thereby reduce infiltration. With improved subsidence control there is less chance of leakage around the mine seal which could lead to increased acid production or complete dam failure. However, since water is the transporting medium for the fill slurry, mine flushing can cause an increased hydraulic head and excess volume of water.

Underground Mine Backfilling

Underground mine backfilling accomplishes two purposes. First, by backfilling with crushed mine and milling wastes, surface stockpiles are reduced or eliminated and a potential source of leachate pollution is eliminated. Secondly, damage from surface subsidence, as well as overlying mine subsidence, is alleviated, and mine fires can be controlled. In addition, subsidence control will decrease infiltration through fracture overburden, as well as restrict the transportation of pollutants through fractured barriers in the mine. This practice has been carried out in both active and abandoned mines.

Abatement of acid mine drainage from mine backfilling has not been documented. However, given the known parameters required for acid production, the restriction of air and water from entering the mine through any technique will necessarily be beneficial.

Three methods of refuse injection, all of which use hydraulically placed solids, are commonly in use: 1) controlled flushing; 2) blind flushing; and 3) pumped slurry. Controlled flushing is used in accessible mines, either active or inactive, and utilizes workmen to place the solids in a uniform manner through the use of horizontal pipes connected to the vertical borehole injection point. Blind flushing is used in mines that are inaccessible to the safe entry of workmen, and is accomplished by sluicing solids into the vertical borehole until the subsurface mine opening refuses to accept any further injection. Blind flushing does not achieve complete subsurface mine opening filling between boreholes, requires substantially more boreholes than controlled flushing to "backfill" a given area, and is therefore considered to be less effective than controlled flushing.

However, backfilling of inaccessible mines was and is a pressing need, leading to the development of the third, "pumped-slurry" technique. In this technique, solids ranging from sand to crushed mine refuse are placed in suspension in mixing tanks and injected through the use of a slurry pump into the mine workings via injection boreholes. This method is vastly superior to blind flushing from a "deposited material per boreholes" viewpoint, i.e., a top quality of as much as 144,753.3 cu. m. (189,319 c.y.) of refuse has been placed through a single borehole, as compared to a normal blind flushing emplacement of from 15.3 to 764.6 cu. m. (20 to 1,000 c.y.) per borehole.

A comprehensive, enforced program of controlled flushing backfilling in the mined out portions of active mines would result in the most effective alleviation production of acid mine drainage. This would be achieved through reduced overburden fracturing and subsidence which significantly decreases the amount of water and air available to react with acid forming materials present.

Effects of Mine Pool Fluctuation on Subsidence

To determine the effects of mine pool fluctuation, it is necessary to first understand the mechanics of subsidence. Subsidence occurs when the ground surface sinks or depresses in response to undercutting its natural support through deep mining, washing out or dissolution of soluble strata (i.e., cavities in limestone). The potential for subsidence is mainly determined by the extent of deep mining, attitude and condition of the mined beds, and thickness and lithology of the overburden. The extent of mining also governs the limits of subsidence in that vertical surface deformation cannot exceed the height of the subjacent mine voids.

When deep mining is concluded in an area, the mine is sealed and left to inundate through the downward percolation of groundwater, thereby forming "mine pools." Depending on the effectiveness of the seal and the amount of water available (the chief source of groundwater is rainfall), the mine void will be flooded. According to a report prepared for the Appalachian Regional Commission (A. W. Martin Associates, Inc., 1975), restrictions which impede flow between entrance to and discharge from a mine are the critical subsidence-inducing factors, since they create abnormally high hydrostatic heads. This pressure build-up will increase the probability of subsidence by triggering immediate collapse of weakened roof rock or promoting rapid deterioration of fractured but otherwise stable overburden. Roof collapse is then the first stage of subsidence. These deteriorating effects are enhanced by fluctuations in the mine pool levels.

The variations cause "piping" or removal of fine, interstitial materials in the fractured overburden and will subsequently reduce or eliminate the frictional forces previously preventing roof collapse.

It has been documented in Pennsylvania Anthracite region reports (A. W. Martin Associates, Inc., 1975, Ash and Westfield, 1946 and Ash et. al., 1949) that water levels in that area's collieries fluctuate periodically, and shortly thereafter, (1-2 months in most cases) some degree of subsidence has been recorded.

Periodic changes in mine pool height will occur when the rate of water flow into the mines exceeds the discharge. Logically then, the majority of subsidence incidents will be preceded by peak or abnormally high precipitation periods. This theory is supported by the number of subsidence cases reported in the northeastern Pennsylvania coalfields, immediately following tropical storm Agnes in 1972. Coal towns like Scranton, Wilkes-Barre, and Hazelton are still repairing damaged streets and buildings which overlie the mined out anthracite seams. Repair crews there are presently attempting to replace support to the weakened roof rock through backfilling the mine void, a remedial, support measure discussed further in a later section of this report.

Reducing the effect of mine pool fluctuation-induced subsidence is a difficult task since the primary requisite of subsidence is prefractured roof rock or structurally weak overburden.

Presently, flooding a mine is deemed necessary to eliminate the production of acid mine drainage. This limits subsidence remedies to the area of overburden support. It is in this field that present research is being conducted, especially into modifications of the previously mentioned "backfilling" or "hydraulic stowing." Pressure pumping slurries of sand or crushed waste rock into abandoned mines has alleviated some support problems, but has not been entirely successful. Neither has this method been totally conducive to efforts to retard acid water formation since it causes increased hydraulic head pressure and seepage on and around the mine seals. A combination of hydraulic backfill and a reinforced mine seal would aid in solving both problems, providing the outcrop barriers and roof rock are thick and strong enough to adjust to the increased water pressures.

REPRESENTATIVE CASE HISTORIES

Case histories illustrating closure techniques, their effectiveness in preventing health and safety problems, acid production and subsidence, and representative costs for construction are reviewed in this section. As previously mentioned, many contacts were made as part of this project to gather information concerning mine closure regulations and liabilities. Contacts were also made with governmental agencies and the mining industry to obtain information on experiences with mine closure methods (see Appendix). The case histories (indexed on Table 9 and described on Table 10) have been gathered from these various sources to illustrate the effectiveness, shortcomings and economic feasibility of present-day coal and non-coal mine closure methods. The case studies which are listed and discussed on Table 10 reflect experience with coal mines only. There is so little experience with sealing of metal/non-metal mines, that information is not included in the table, but is discussed under a separate heading "Non-Coal Mines" in this section of the report.

Nearly all the case histories studied and presented here represent sealing programs for abandoned underground mines. These are mostly older mines which have been discharging acid mine drainage or have been left open or otherwise hazardous to the surrounding populace before more stringent legislation was passed requiring more adequate sealing procedures. Active operations obviously would not be sealed totally, although current endeavors are underway to seal-off abandoned sections of active mines to abate acid production through inundation of pyritic or otherwise acid producing materials. In Pennsylvania, for example this practice has been or is being practiced at several mines but construction plans and structures require inspections and approval by the Commissioner of Deep Mine Safety. However, limited information is available for those sites.

The following is a discussion of some of the more detailed abandoned mine case histories that were found with sufficient information available for evaluation.

COAL MINES

Air/Dry Sealing Cases, Pennsylvania

In 1932 a pilot project was initiated to confirm an observed but untested phenomenon concerning mines with caved or otherwise sealed openings. These mines seemed to be discharging effluent that contained little or no acidity. It was ascertianed that the limited supply, or complete lack, of oxygen retarded the oxidation of sulfide minerals and consequently the formation of effluent pollutants. Hence, the pilot project was initiated to air seal three mines and monitor their discharges. The results which showed a reduction in acid production prompted extensive projects by the Work Progress Administration and the Civil Works Administration to air seal known abandoned mines currently discharging acid mine drainage.

As a result of the above programs, which covered the periods from 1933 to 1939, and from 1947 to 1949, at a cost of $5.5 million dollars, air and dry seals were placed in the openings of several thousand mines.

A typical mine was sealed by placing dry seals in all openings except for the lowest one, where an air seal was placed to allow mine drainage to escape. Two typical dry seals and air seals for the 1930's sealing project are shown on Figures 3 and 6.

Unfortunately, the effluent evaluation program was not carried over from the pilot sealing program; therefore, the effectiveness of the overall program was never determined. The following results, however, were attributed to the sealing program.

- The U. S. Public Health Service estimated a 28 percent reduction in the acid load of the Ohio River.
- The Pennsylvania Sanitary Water Board partially attributed a decrease in acidity in the Monogahela River to the sealing program.
- It was claimed (agency unknown) that the program so reduced the mine drainage problem in Pennsylvania that in various streams fish life returned and water was used for industrial and domestic purposes.
- A West Virginia report claimed that as of February 1, 1963, a reduction of 77.8% occurred in the acid load discharging from 345 sealed mines.

To illustrate the extent of this federal mine sealing program, in just two years, from October 1, 1935 to September 1, 1937, a total of 3,171 mines and 84,844 openings were sealed. The states in which the program took place and the magnitude and cost of the effort is shown below:

State	Mines Sealed	Openings Sealed and in Progress	Total Expenditures
Alabama	31	660	$ 45,396.37
Indiana	60	910	124,258.85
Kentucky	488	2,625	210,046.90
Maryland	19	45	38,351.43
Ohio	1,769	18,111	743,690.57
Pennsylvania	468	58,212	1,637,450.12
West Virginia	336	4,281	528,604.77
Totals	3,171	84,844	$3,327,799.01

A further analysis of the individual costs reveals that the:

- Average cost per mine sealed was $1,049.45
- Average cost per opening sealed was $39.22
- Average cost per labor hour was $0.496

These costs reflect the 1938 era, and could not be realistically brought up to date.

Pennsylvania was one of the few states which continued to seal mines, and to some extent monitored effluent after completion of the Federal Sealing Program. Further data from Pennsylvania sealing efforts reveal that:

- Between 1937 and 1950, the Youghiogheny River showed a decrease in acid load from 789 to 168 metric tons per day (870 to 185 tons per day). As a result, the city of McKeesport again began taking its domestic water supply from the Youghiogheny.
- The Borough of Barnesboro began taking its water supply from the discharge of a sealed mine.

- The Casselman River, formerly heavily polluted with acid mine drainage became alkaline and supported fish life. However, this result was reversed by the discharge from later, active mining operations.

- In several areas in the central part of the state, water flowing from sealed mines was being piped directly to homes and used for domestic purposes.

No technical information is presently available to substantiate these results.

In 1947, the Pennsylvania Department of Health's Sanitary Water Board undertook a study to determine the effectiveness of air sealing in reducing acid coal mine discharges. Seven mines were chosen as a control, with water samples collected and analyzed from 1947 to 1960. The mines were air sealed in 1949 to 1950. The data collected during the study did not substantiate the results of the thirty's sealing programs and it was concluded that air sealing, although correct in theory, did not result in a significant reduction in mine effluent acid load, or mine atmosphere oxygen content.

It is generally hypothesized that the parameters required for successful air sealing of a mine are:

- The ability to locate and effectively seal all air and water passages into the underground mine complex.

- Choosing a mine located beneath a thick, structurally competent overburden, that is not likely to be affected by subsidence as a result of mine roof falls.

Assuming the mine fits these parameters, various factors will still be evident which could cause partial failure of mine drainage abatement. A constant change in atmospheric pressures outside the mine cause pressure gradients to form, resulting in air flow into and out of the mine. Rainfall, percolating through the overburden, could also contribute to the oxygen that is available to produce acid mine drainage.

One site specific case which has been thoroughly documented in the literature is the air sealing of the Decker No. 3 mine — a 31.2 ha. (77 ac.), abandoned, highly acid drift mine, 64.4 km. (40 mi.) northeast of Pittsburgh, Pennsylvania. The mine was sealed under the auspices of the U.S. Bureau of Mines between November 1965 and May 1966. Eight separate seals, seven of which were dry seals and one of which was a true air seal, were constructed. The seals were built on concrete footers, anchored into the roof and ribs of the opening, and protected against acid attack with a urethane foam coating.

In addition to the entryway sealing, two additional dams were constructed, one in the main drift and one in the main air course, as well as backfilling, compacting, grading, and seeding of two strip mines on the outcrop, and clay sealing of a 9.1 m. (30 ft.) diameter subsidence hole and clay sealing and grouting of a badly caved drift, was required. The seals were augmented structurally by timbering on either side for roof support. This mine was chosen primarily due to the following favorable characteristics:

- The mine was overlain by competent strata of siltstone and sandstone.
- The overburden was 30.5 m. (100 ft.) to 61 m. (200 ft.) thick over more than 50% of the mine area [average depth is 22.6 m. (74 ft.)].

- Mine roof conditions were very good.
- Most of the pyritic sulfur from which the acid discharge would be formed occurred in the bottom portion of the coalbed and in the top layer of the underclay.

This mine produced for a short time in 1929, again in 1942, and then from 1950 to 1959, on an Upper Freeport seam that is 0.9 m. (2.95 ft. thick), lying on a 4° dip from an east-west strike. This mine is, of course, located above drainage, and there is no other mining in proximity to it which could radically change existing conditions.

According to Michael Baker, Jr., (b. 1973), results of the chemical analysis taken before and after sealing show an increase in the mean value of pH from 3.1 to 3.4 and a decrease in the mean concentrations of acidity, sulfate, calcium, magnesium, and total iron. After sealing the oxygen content in the mine was lowered from 20.9 percent to about 17.0 percent.

After sealing a reduction of 26.5 million liters (7 million gallons) in effluent volume and a reduction of 150 mg/l in effluent acidity were attributed to the air sealing. The reduction in oxygen concentration seemed to stabilize the mine, and thus, decrease the variance in total acidity of the effluent. Additionally, average monthly total acidity and flow rates of the mine effluent before and after sealing show a slightly lower volume of effluent after the mine was sealed. Evidently some surface opening infiltration was diverted by the seals.

The Decker No. 3 Mine is the only mine where all three of the major pollutants (acidity, sulfate and total iron) were reduced both in concentrations and discharge load. These pollutant concentrations decreased by an average of 50%. However, the quality of the effluent from the mine as compared to mine effluent guidelines, and/or water standards, is rather poor. The acidity is still higher than the alkalinity, the pH is lower than the present effluent guideline of 6.0, sulfate concentrations are higher than the 250 mg/l that is acceptable to drinking water standards, and total iron is above the mine effluent limit of 3.5 mg/l (Bucek and Emel, 1977).

Specifically, Decker No. 3 had a 57%, 31%, and 71% reduction of acidity, sulfate, and total iron, respectively, in its effluent pollutant concentration, and an 81%, 70% and 81% reduction in its pollutant output quantities of the same parameters, apparently as a result of the air sealing effort.

The monitoring record of Decker No. 3 is the most extensive of the mines sealed in the late 1960's study. A total of 343 observations were conducted for pre-sealing acidity, sulfate and total iron loads, as well as concentrations, and 173 and 135 observations were taken for post-sealing chemical concentrations and loads, respectively.

Almost seven years after the monitoring of the site by the U.S. Bureau of Mines, chemical analysis of two samples indicated a marked reduction in pollutant concentrations and loads. The acidity concentrations were 17.6 and 1.6 mg/l, while pH levels were above 5.5. Alkalinity was measured at 26.2 and 10.9 mg/l, and concentrations of sulfates and total iron decreased to 210.0 mg/l and 41 mg/l levels.

A complete cost breakdown for the sealing program at the Decker No. 3 Mine is presented below:

Item	Cost
Timber, treated 56.9 cu. m. (24,390 bd. ft.)	$ 5, 146.00
Urethane foam 908 Kg (2,000 lb.)	3,510.00
Masonry Blocks - 2,002	524.00
Pipe - 51 m (167 ft.)	528.00
Concrete - 21 cu. m. (28 cu. yd.)	504.00
Miscellaneous	288.00
Total Material	$10,500.00
Equipment (including operator)	8,960.00
Labor (5,000 man-hours)	30,000.00
Total Equipment and Labor	$38,960.00
Miscellaneous Cost:	
Sealing 2 strip pits (1.2 hectares, [3 acres]) 1 surface subsidence, and 1 caved entry	7,000.00
Grading access roads and portal areas	960.00
Total Miscellaneous Cost	$ 7,960.00
Grand Total Costs	$57,420.00

The average cost of the seven dry seals was $5,089.00. The cost of the air seal was $14,800.00, due largely to the size of the entry [6.7 m. (22 ft.) wide and 1.5 m. (5 ft.) high], as well as the multiple walls and foaming (urethane).

Hydraulic/Multipurpose Sealing Cases, Pennsylvania

In 1973, Gwin Dobson and Foreman Inc. performed work for the U.S. Environmental Protection Agency under the general heading of the Pennsylvania Operation Scarlift. This program was designed to search, inventory and remedy all problems pertaining to and/or incurred by acid mine drainage from abandoned surface and underground mines in the Moraine State Park Area of Butler County, Pennsylvania. Here Gwin, Dobson and Foreman Inc. were charged with the design and supervision of installation of 65 mine seals in 19 mine complex areas.

The Moraine State Park Area has been extensively deep mined in the Middle Kittanning Coal Seam since the early 1900's. One mine, the Salzano Ross, was the only active operation remaining at the time of condemnation for the park. This mine is presently 75% inundated. All mines were developed to the rise with a maximum dip of 3° to the southeast. The coal is 76.2 c.m. (30 in.) — 101.6 c.m. (40 in.) thick and is characterized by high ash (10%), moderate sulfur (1%) and a low to moderate heating value (10,000 to 12,000 BTU's). Overburden averages 30.5 c.m. (100 ft.) thick and is comprised of shale, siltstone, and sandstone in a cyclic sequence. The pyrite content in the sandstone roof directly above the Middle Kittanning is 1%.

Streams in the Moraine State Park Project Area were receiving approximately 22.7 kg/day (50 lbs./day) of acid, contained in the effluent from the deep mines and 187 ha. (462 ac.) of strip mine workings in the park. Closing the deep mine openings required 65 hydraulic seals, all of which had to be remotely installed due to caving of the abandoned mine entries. Two bulkhead walls were formed by pumping limestone aggregate through boreholes drilled across the mine heading and into rib-rock. These bulkheads were pressure grouted, including the rib-rock, and then a grout center-plug was added between the two bulkheads. Curtain grouting operations were initiated to reinforce the outcrop barrier, as well as sealing of all boreholes and airways with grout plugs to insure that the mine was water and air tight.

The flooded heights or levels and water quality data from 24 observation holes were reported on a periodic basis starting after the completion of the applicable mine seals. Effectiveness of the seals was most readily seen in the quality of the water in the Park's Lake Arthur (Table 10).

Two subsequent field inspections were performed since the actual mine closure procedures were initiated. One in September, 1973 in dry weather conditions, and the second in March, 1974 in wet weather conditions. The water quality results were relatively the same as in 1971 which gives evidence that hydraulic sealing was an effective method for inundating mines and abating acid mine drainage production in this area.

The double bulkhead sealing of deep mine openings in Morraine State Park appears to have been a successful operation. Ten years have passed since closing the nineteen mines. To date none of the sixty-five seals have failed or come to a state of severe disrepair. In every instance of partial or total mine inundation, a marked decrease in acid production has been achieved, as evidenced by the quality of water maintained over the past decade in Lake Arthur.

Of all mines closed, the Fox, Salzano Ross, Lindey and Kildoo showed the most promising water quality effects from their combined eighteen (18) constructed seals. More specifically, the Fox Mine demonstrated an 84% decline in acid production, one year after closure, decreasing the acid load from 12.7 Kg/day 28 lbs./day to 13.6 Kg/day (30 lbs./day). This reduction was the result of totally inundating approximately one-half of the mine complex, preventing the majority of pyritic materials present from reacting with oxygen and forming sulfuric acid. The extent of inundation was calculated by assuming 3.4 m (11 ft.) hydraulic head over the mine pool area with uniform development of the seam dipping 3°.

Similarily the Salzano Ross Mine showed an 83% acid load reduction from an unacceptable 66.7 Kg/day (147 lbs./day) level to a more reasonable 5.9 Kg/day (13 lb./day) within the first year of closure. Using the mine pool evaluation measurements taken at the various observation wells at this site and assuming a uniform mine development over a seam dipping 3° it was calculated that 75% of this mine complex was flooded, therefore producing such a noticeable acid load reduction.

At the Lindey mine site, acid production was impeded as a decline from 8.2 Kg/day (18 lbs./day) to 5.4 Kg/day (12 lbs./day) was recorded in the first year of mine closure. This decrease however was not accompanied by a charge or drop in rate of discharge, even though mine pool elevation measurements indicated total inundation was achieved soon after sealing. Such circumstances would tend to indicate a failure or leakage near the top of the mine seals, but not damaged enough to prevent isolation of the pyritic material from reaction inducing oxygen.

Lastly, a most notable change in acid production was evidenced through measurements taken at the Kildoo mine. A substantial decrease from 46.3 Kg/day (102 lbs/day) to 13.6 Kg/day (30 lbs/day) was recorded during the first year's observations as well as a 60% reduction in the effluent discharge rate.

The successful depletion of acidity in the Moraine State Park Area mines can be attributable to the effectiveness of the double bulkhead seals installed at each site. Though a variety of roof and rib-rock conditions existed in the openings, the unique remote installation methods provided a means of securing the bulkheads firmly enough to bring about sufficient inundation of the reactive materials.

A major benefit of the double bulkhead seal lies in its strength or resistance to failure due to excessive head pressures. The increased strength over such closures as single bulkhead, or permeable aggregate seals makes this type of seal preferable to provide high health and safety levels.

Hydraulic/Multipurpose Sealing Cases, West Virginia

A second pertinent study was performed for the EPA by the Halliburton Company of Oklahoma. The study concerned the investigation and closure of Mine #62-008, an abandoned drift mine near Lost Creek, in Harrison County, West Virginia (Halliburton Company b, 1979). At this site, 8.1 ha. (20 ac.) in a 60.7 ha. (150 ac.) tract were mined during the 1900's from 5 drift openings. A total of 250,000 tons of coal were produced underground until abandonment and subsequent stripping of the outcrop in the early 1930's.

The majority of mining was done in the Pittsburgh Seam. Approximately 2 m (6.5 ft.) thick with a high (3.1%) sulfur content, this mine was developed, by room and pillar method, in an updip direction along the gently sloping (4°) coal seam. The overburden consists of approximately 22.9 m (75 ft.) shale, 18.3 m (60 ft.) sandstone and 9.1 m (30 ft.) limestone. The overburden or roof-rock was stable with little threat of subsidence, especially with the employment of Room and Pillar mining.

Sealing of three of the mines produced the desired inundation this high sulfur coal. When constructing these seals, three different types were used; a permeable limestone plug, a double bulkhead seal, and a single bulkhead seal. Such variety made it possible to compare the results of the individual seals and judge the relative effectiveness of each closure technique. The single and double bulkhead seals held up well with few leakage problems, leaving the "permeable plug" to handle the majority of the drainage and head pressure. The limestone aggregate plug, the most innovative of the three seals, was constructed by pneumatically injecting limestone chips into the mine opening and, utilizing vibration-compaction, building a pyramid-like wall from floor to ceiling. Alternating layers of 1.9 cm (.74 in.) and 3.8 cm (1.5 in.) aggregate were used to allow acid mine drainage to infiltrate and react with the neutralizing, alkaline material. A dual purpose was achieved this way, by raising pH and alkalinity levels which in turn promoted the oxidizing and precipitating of ferrous iron from solution. The precipitate, by design, coated and clogged the pores between the limestone chips creating a watertight seal, although the lack of sufficient pre-sealing monitoring prohibited an in-depth, statistical validation of the seal's effectiveness. An analysis of post-sealing effluent quality indicates a slight but consistent decrease in acid production and sulfate concentrations registered in 1975 at this site. This was attributed to settling and subsequent separating of the aggregate pile from the roof and sides of the mine wall thereby allowing leakage over and around the wall. However, this seal is presently in good working condition and registered pH levels of 6.6 over an original 3.6 reading indicates that acid water is continuing to be neutralized.

A further example of the use of a permeable limestone seal in conjunction with a double bulkhead seal is the RT-52 Mine of the Coalton Complex, one of the mines in the Elkins Demonstration Project near Coalton, West Virginia. This project was undertaken by the Halliburton Company under contract to the U.S. EPA (1977).

The RT-5-2 mine was active between 1904 and 1950, and was closed in September 1969. The entire Coalton Complex produced 13,475,000 metric tons of coal from the Lower Kittanning seam. This seam dips north and west approximately 10° and attains a maximum thickness of 3 meters (9.8 ft.) deposition. The RT-52 lies below drainage in an area the receives an average annual precipitation of 109.7 cm (43.2 in.). This small drift mine (0.14 Km^2) has approximately 39 m (128 ft.) of overburden, consisting of 23 m (75.5 ft.) of shale, 13 m (42.7 ft.) sandstone, and 0.9 m (3 ft.) of calcareous rock.

of overburden, consisting of 23 m. (75.5 ft.) of shale, 13 m. (42.7 ft.) sandstone, and 0.9 m. (3 ft.) of calcareous rock.

A double bulkhead seal was constructed in entry #1 of the RT-5-2 Mine, consisting of bulkheads of quick-setting self-supporting cementitious materials, and a core composed of limestone aggregate that was made impermeable by grouting with light cement.

This mine had a pre-sealing flow rate in the range of 36 to 2,087.3 lpm (9.5 to 551.5 gpm) which is considered a high rate of flow. The double bulkhead seal was, however, successful and no leakage from the opening was apparent when inspected in September, 1971. The hydraulic head behind the seal stabilized above 2 m. (6.6 ft.) after January, 1970.

Due to the increased water elevation in the mine, a previously unknown opening, RT-5-2A, started discharging. It was determined that a permeable limestone seal would be used to control acid mine drainage pollution from this new discharge point. The work was performed by constructing a seal of graded limestone aggregate and agricultural lime in the drift. The annular space above the seal and below the mine roof was grouted to prevent possible overtopping of the seal.

The quality of the water in the mine deteriorated considerably after the sealing and flooding of the mine. Acidity increased from the pre-sealing average by 61%, rising from 683 mg/l to 1107 mg/l. Sulfate concentration increased by 118%, from 660 mg/l to 1438 mg/l and that of the total iron content from 212 mg/l to 502 mg/l for an increase of 137%.

This water was allowed to discharge through the permeable limestone seal (RT-5-2A) between 1971 and October 1975. The neutralizing effect of the initial effect of acid mine drainage reacting with the fresh, alkaline material, iron in the form of ferrous hydroxide begins to precipitate out. This precipitate is not only a cementing agent between but also a coating on the aggregate which impedes reactivity with incoming acid water and causes that initial rate of neutralization to slow or level off. Peak seal performance findings indicate that the aggregate seals are much more effective in mine atmospheres that produce more ferrous or reactive ions than the ferric or stable ions. Additionally it is necessary to obtain a high placement density or compaction level in the construction of the aggregate bulkhead so as to minimize shrinkage/settling and thereby maximize inundation.

Installment costs incurred by the Halliburton company in two acid mine drainage abatement projects in the late 1960's were $3,048 and $8,463 per seal. However, Michael Baker Jr., Inc. (1973) reports that an estimate of $7,500 per aggregate seal was required. Updating this cost to present day figures gives an estimated $12,900 per 1979 seal.

Of the remaining two openings at mine #62-008, a single cement bulkhead seal was constructed in the #4 portal and a double bulkhead seal in #5. The single bulkhead was installed November of 1968, again by pneumatic injection. In this case, a thick slurry of quick-setting bentonite and sodium silicate was pumped into the mine and allowed to completely fill an aggregate bulkhead (larger aggregate than used for the permeable aggregate plug) extending from the floor to the mine roof. The Halliburton Company performed pre- and post-sealing effluent sampling and testing. The results showed the bulkheads effectively eliminated all the permeable seal had a significant impact on the acidity of the mine discharge, accounting for an 86% decrease. By June 1971, alkalinity had increased by over 300% and was generally higher than acidity. The total iron concentrations decreased from pre-sealing discharge levels of 212 mg/l to 160 mg/l.

Comparison of the total averages of the pollutant outputs for the pre- and post-sealing sampling periods indicates 99% reduction in acidity, 98% reduction in total iron, and 96% reduction in sulfates. Variability of the effluent parameter has been reduced as well.

Due to the concern that the considerable hydraulic head behind the seals could cause danger to the health and safety of the surrounding populace, the pipes used for monitoring water quality within the mine have been opened and allowed to drain freely. The two closures are now functioning as air seals and are both in good condition. Acid and total iron concentrations have risen from post-sealing to pre-sealing levels again, however, sulfate concentrations are lower than either the pre- or post-sealing mines.

In support of the conclusions presented above, another limestone aggregate seal was constructed and monitored in a West Virginia coal mine. The "unknown" mine near Stewartstown showed marked improvement in effluent quality over the years of observation and analysis performed by the EPA.

Results of this type of mine seal indicate an immediate increase in pH and alkalinity with decrease registered in total iron and acidity. After appreciable drainage from the portal until leakage was observed in late 1969. By 1975 this leakage had increased to a flow of 60 lpm (16 gpm) but the acidity concentrations were still greatly decreased. This decrease is attributable to sufficient inundation of the coal and associated sulfur minerals, maintained by the single bulkhead. Measurements taken at observation wells behind the seal indicated an established head of 1.1 m (3.5 ft.) to 1.4 m (4.5 ft.) maintained since the year following seal installation. Therefore, even though the closure failed to prevent water seepage, it is still regarded as a successful venture since acid production was cut drastically.

The cost of installing an accessible entry grouted aggregate (2B stone) seal is estimated at $3500,while a remotely placed grouted aggregate (6B stone) seal would cost approximately $2100.

Similar in construction to the single bulkhead in opening #4, is the #5 double bulkhead. At this adjacent site, two pyramidal stackings of 2B gravel chips were constructed and grouted with a bentonite and sodium silicate cement. The center space or core area between the two bulkheads was then injected with an inexpensive cement forming a roof to floor plug. Once sealed in 1968, no leakage was observed from the #5 opening until late 1970 when an average flow of 0.8 l/min. (0.2 gal./min.) became apparent and continued until October, 1975. The near-complete containment of mine water behind the seal has eliminated the acid production problem and cut pre-sealing pollutant outputs by more than 90 percent. A level of total inundation was maintained in most of this 2 m (6.5 ft.) mine void from one year after closure to the present time.

Together with the results of the Morraine State Park Study, previously discussed, the double bulkhead seal used in mine #62-008-5 has shown the most promise for successful mine closure and inundation.

Single bulkhead seals have rarely been effective for more than two years. This is especially true of seals that have been installed without the benefit of curtain grouting. Consequently, it has been widely accepted that a 15.2 m linear area (50 ft.) on both sides of the hydraulic seal, regardless of type, should receive a curtain grouting treatment. This would add an average cost of approximately $5,800.00 to the construction cost of a seal.

One site specific example of a successfully executed installation of a single bulkhead type seal in a coal mine is Mine No. 40-016, an abandoned drift mine which worked the Pittsburgh and Redstone coal seams in Harrison County, West Virginia. The mine was in operation from 1904-1930, and more recently both seams have been strip mined. Pittsburgh coal in this area is characteristically 1.8 m (6 ft.) to 2.1 (7 ft.) thick. with a 3% sulfur content, a shale layer of the same thickness, plus a limestone deposit of 1.2 m (4 ft.) to 1.5 m (5 ft.) thick, separates the Pittsburgh Coal seam from the overlying, 1.8 m (6 ft.) thick Redstone coal. Two meters (6.6 ft.) of shale and 5.5 to 6.1 m (18 to 20 ft.) of sandstone completes the geologic section to the topsoil bench.

Mine openings #1 and 2, in the Pittsburgh seam, were determined to be the most effective closure points. Accordingly, it was decided to use single, cement-grouted aggregate bulkheads in these openings. The seals were constructed by pneumatically placing 1.9 cm (.75 in.) to 3.8 cm (1.5 in.) graded limestone in the mine opening, in conjunction with .95 cm (.37 in.) aggregate to contain the grout, and their pressure grouting the aggregate to form a solid seal (see Figure 12). The cost of the seals in this particular mine averaged $8,848.00 per seal, which included opening the mine portal to the original dimensions and flushing with water a pressure of 105,465 kg/m^2 (150 psi). Construction was completed in December, 1967.

Effluent from the mine, which flows into Stone Pot Run and further into Lost Creek, was discharging at a rate of 26.5 to 567.7 l/min. (7 to 150 gpm) prior to the sealing effort, in spite of the fact that the major area of the mine lies above drainage.

Immediately following installation of the seals, flows were reduced to 11.4 l/min. (3 gpm) from Opening No. 1 and 40 l/min. (9.5 gpm) from Opening No. 2, an average flow rate reduction of 85%. It was decided then to grout the seal perimeters in an effort to further reduce the flow. This remedial grouting reduced the flow to 8.3 l/min. (2.2 gpm) from Opening No. 1, and 3.6 from Opening No. 2. This was a 17% increase in effectiveness over the original post-sealing discharge.

A second attempt at remedial grouting was then undertaken, reducing the flows as follows:

7.6 l/min. (2.0 gpm) for Opening No. 1
8.3 l/min. (2.2 gpm) for Opening No. 2

This was a 27% decrease in flow over the original grout sealing effort, and a 37% decrease when compared to the original, nonperimeter grouted seal.

A third grouting procedure at Opening No. 1 had no further effect on the discharge; therefore, no third grouting effort was attempted at Opening No. 2.

Mine water samples were collected by Halliburton between September, 1968 and August, 1969 and water levels (hydraulic head) behind the seals were also monitored by Halliburton. The seal was apparently instrumental in reducing the acid discharge from Opening No. 1 to 16.8 kg/wk. (37 lbs./week) from 30.4 kg/wk. (67 lbs./week), a reduction of 42%. Likewise, a 64% reduction, from 37.6 to 13.6 kg/wk. (83 to 30 lbs./wk.) was achieved at Opening No. 2. Total iron output was reduced about 35 to 40 percent. Only one sampling for the pre-sealing water quality is available, and the above values should be evaluated with some caution.

In summary, for about 2½ years the seal was effective in greatly reducing acid mine drainage. However, by 1971 both seals were leaking at a combined rate of 67 l/min. (17.7 gpm) and during a 1975 flow analysis, it was determined that Opening No. 1 was leaking at a rate of 95 l/min. (25.1 gpm). These are not, however, as severe as the pre-sealing average flow rate of 177.9 l/min. (47 gpm).

Two sampling points, monitored in October, 1975 and March, 1976, have indicated that although the flow rates, total acidity and iron loads have increased, the pollutant concentration has been decreasing. During both sampling periods, alkalinity was measured as higher than acidity. Acidity and iron outputs have not reached pre-sealing levels.

The proximity of this site to a surface mining operation employing significant blasting, with the resultant disturbance of the mine water recharge area, could have contributed to the partial failure of this seal.

Clay Sealing Cases

Clay seals have been used, successfully, to prevent the entry of air and water into air sealed mines; however, very little data exist concerning their capability to eliminate mine discharges and affect inundations of underground mines.

Various projects which have utilized or contemplated using clay seals have experienced estimated costs in the range of $1,200.00 to $4,000.00 per seal. These costs, adjusted for construction cost inflation to 1979's prices, would approximate $1,900.00 to $6,300.00 per seal (1972 to 1979).

Selected site specific examples of the use of clay seals are documented from Moraine State Park, Pennsylvania, the Elkins Demonstration Project in West Virginia, and the Shaw Mine Complex in Pennsylvania.

The Moraine State Park project was a major undertaking, which included the clay sealing of 14 deep mine drifts, 6 deep mine openings, 2 gob piles, and a test pit, for a total of 23 closures. The use of these seals, in conjunction with other remedial work, has apparently had a very beneficial impact on the environment of the park's Lake Arthur. Although some of the clay-sealed areas were points of active acid mine discharge, they were areas where water entered the mines and could have become sites of pollution after inundation of the mines. Utilized in this manner, clay seals have a positive value in reducing the volume of discharge and also have decreased the incidents of surface subsidence by preventing storm water from entering the mine.

The Elkins Demonstration Project, located in the Roaring Creek-Grassy Run area of Randolph County, West Virginia, involved the sealing of forty-one (41) openings with clay. The project was a cooperative effort between federal agencies and the State of West Virginia, and was primarily an effort to evaluate air sealing of abandoned underground coal mines.

A combination of double bulkhead, permeable limestone, dry, and clay seals were employed at this mine complex. Located in the Kittanning coal seam, the overburden in this area generally consists of 22.9 m of shale, 13.1 m of sandstone, and .9 m (3 ft.) of calcareous rock. The coal seam, containing approximately 2.0 percent sulfur, is 2.4 m (7.9 ft.) thick. The rock beds dip approximately 10 degrees. Average annual precipitation is 109.2 cm (43 in.), with the mine elevation located near drainage.

Clay seals were utilized where surface mine highwalls were badly fractured, as well as where the deep mine passages had been intercepted by stripping operations. The seals were constructed by placing 0.6 meter (2 ft.) layers of clay against the highwall and compacting with a vibrating sheepsfoot roller. The majority of the seals were placed on the updip side of underground mines; however, during sealing of a small abandoned underground mine, two clay seals were constructed on the downdip outcrop. Upon complete hydraulic sealing of the mine, with the resultant rise in interior water level, water flowed up through the overburden in the seal areas over the top of the seals, eroded the seals and allowed the mine pool to drain.

Of the 41 seals placed, costs were tabulated for only 16, ten of which averaged $950.00, and six of which averaged $2,360.00. The higher priced seals involved a greater haulage distance from the borrow pit to the construction site. These are 1972 construction costs, which when adjusted to 1979 prices would average $1,500.00 and $3,720.00, respectively.

A discussion of the acid mine drainage abatement achieved in conjunction with this demonstration project would not reflect the use of the clay seals since the discharge monitoring point was at a permeable limestone seal. Pre- and post-sealing chemical monitoring are discussed under the case histories of permeable limestone seals.

One extensive coal mining complex in which clay was utilized exclusively in an attempt to hydrologically isolate sections of the mine was the Shaw Mine in Somerset County, Pennsylvania. Overburden above the abandoned deep mine was excavated in a box cut fashion, the remaining Redstone and Pittsburgh coals removed, and clay barrier seals constructed in the cut to flood portions of the underground mine. Pennsylvania projects SL 118-2B and SL 118-3-2 were involved with land restoration in the Shaw Mine Complex Area, including contour backfilling, and planting and seeding.

Approximately 64,991 cu. m. (85,000 cu. yd.) of clay were installed facing and extending along the downdip side of the cuts for approximately 1066.8 m (3,500 lin. ft.). The clay was installed in 30.5 cm (12 in.) layers and compacted by a dozer and haul trucks during spreading and hauling of the clay. The dimensions of the seal were approximately 6.1 m. at the bottom and 4.6 m. at the top; 1,368,634 cu. m. (1,790,000 cu. yd.) of spoil was moved during backfilling. Backfilling was done coincident with installation of the clay seal to contain the clay material.

Total cost of project SL 118-2B was $183,800.00, with construction completed in June, 1972. Cost of project SL 118-3-2 was $324,600.000 with a May, 1973 completion date. The 1979 costs would be $290,000 and $512,000, respectively.

Upon completion of project SL 118-3, chemical analyses of the mine discharge were conducted, determining that rather poor quality water was discharging from the mine area at a rate of 94.6 lpm (25 gpm). Pre-sealing analysis was not conducted.

Evaluation of the above applications of clay seals would seem to indicate that their use as a hydraulic seal, although sound in technological theory, does not prove effective. Further research, using hand placed and compacted clay seals in a typical drift, to the rise openings, would be necessary before eliminating this economical feasible type of mine sealing from use.

A mine closure operation using the grout bag seal was documented in Clarksburg, West Virginia at mine No. 14-024A a drift mine in the

Pittsburgh seam. In May, 1967, The Halliburton Company successfully installed a grout bag seal directly in the entranceway where the floor of the mine was shale and the ribs and roof were moderately-fractured coal. The first effluent discharge measurements, taken immediately after secondary grouting of the sides and top, showed a decrease in flow from 68 lpm (18 gpm) to 5.7 lpm (1.5 gpm). An inspection made in late 1971 showed no appreciable leakage between the bag layers; however, the bond between the top bag and the mine ceiling had failed due to the continual deterioration of the fractured roof coal and large unchecked flow has since been discharging. Robert B. Scott (1971) under contract to the U.S. EPA, reported that pH, total iron and sulfates have remained essentially unchanged. However, this seal did achieve a flow rate reduction of approximately 90%, and therefore pollutant loads were decreased in the years before 1971.

As noted earlier, the above cases are limited to abandoned underground mines which have been comprehensively documented in the literature. In nearly all cases studied effluent discharges showed improved water quality when compared to preclosure analyses for the major pollution parameters of pH, iron and sulfate.

NON-COAL MINES

Closure procedures in the metal and non-metal (non-coal) mining industries are not well documented in the literature due to some unique circumstances involved in their operations. "Ore" mines are rarely abandoned or completely shut-down. This is particularly true in the Western

U.S., where it is common practice to mine ore at times of peak market values and then to close-down or lay off operations when market prices decline. Such practices necessitate full-time accessibility to the mine and therefore, restrict sealing procedures to wooden barricades, fences or uncompacted backfill to protect against trespassing and possible liability.

Through numerous communications with representative government and mining industry personnel and non-coal mine operators across the U.S. and in Canada, a survey of ore body characteristics, mining methods and permanent closure procedures was conducted. A complete directory of contacts made is included in the Appendix.

Metal and non-metal mines do not have the same high degree of water accumulation that Eastern coal mines have exhibited. This fact is due mainly to the differences in the mode of occurrence. Coal is a depositional mineral associated exclusively with a sedimentary environment or as in the case of anthracite coal, with additional metamorphism. In either situation, the surrounding geology is usually comprised of permeable and waterbearing rock units, which supply a continuous influx of groundwater to the coal mines through fractures, joints, or direct seepage. Most metallic ores, on the other hand, are formed by or associated with igneous or metamorphic materials or related processes. It is also the nature of pyrite of sedimentary origin to react more readily than the stable, "museum grade" pyrite which is characteristic of igneous associated environments. Therefore, acid production in non-coal mines is often less than that produced in the "ideal" conditions of Eastern U.S. coal mines.

Operations such as the Franklin Zinc Mine of New Jersey Zinc, Inc., New Jersey, the Cornwall Magnetite Mine of Bethlehem Mine Corp., Pennsylvania, the St. Joe Lead Mine of St. Joe Minerals Corp., Missouri, have all been abandoned and sealed using basic .91 m. (3 ft.) thick, reinforced concrete plugs. The primary access to these ore bodies is through vertical shafts from the surface down to some level near the base of the ore body and then through horizontal headings driven into the ore. In this manner ore bodies are mined from the bottom up using gravity to load conveyor belts with channel the ore back to the shafts and up to the surface. Shaft seals are hitched 0.6 m (2 ft.) into roof, ribs and floor, and are supported by 1 inch thick steel rods placed across the opening on 0.3 m (1 ft.) centers. The plug is located down the shaft so that it is keyed into solid rock, and the distance from plug to surface is backfilled, the headframes are dismantled, and the area is regraded and vegetated as a final step.

The Franklin Mine, four shafts extending down to a depth of 762 m (2500 ft.) was abandoned in 1954 due to depleted ore reserves. A drainage of 242.2 l/m was recorded in the area but no treatment was necessary since pH levels were consistently measured in the 8.0-8.4 range. Reasons noted for this good mine water quality revolve around the origin of the zinc ore. A vast majority of the mined zinc oxide and zinc sulfide ores in the world occur in conjunction with carbonate rocks (limestones, marbles) and therefore, mine water is automatically alkaline before discharge. Additionally, what sulfur is present is in the oxide (rare) type of zinc or is chemically bonded and is rendered partically insoluble. Consequently, sealing procedures at this operation have been geared strictly toward safety and liability by making the shaft workings inaccessible.

The Cornwall magnetite mine of Bethlehem Mines Corporation strongly resembles New Jersey Zinc's operation in that the mined magnetite body is a replacement ore in a large limestone bed. This small ore body was developed by a Triassic-aged, igneous intrusion into the carbonate host rock which, through magmatic segregation, cooled and produced ore of commercial quantities. By the time tropical storm Agnes had caused extensive flooding damage to the then active Cornwall operation, it was estimated that only one year or less of minable reserves were left and that pumping would be economically useless. The decision was made in late 1972 to seal the three compartment shafts with reinforced concrete seals. The seals were placed in solid rock and keyed into ribs as described previously. Since no drainage or head pressure was anticipated here, the dimensions of the seal were only 6.1 m x 3.1 m (10 ft.) x 25.4 cm (10 in.) thick. The quality of water in the mine pool was constantly between pH 7.0 and 7.4, so again no treatment or drainage prevention measures were required. Special measures to abate subsidence were also not needed at this site since the panel-caving method of ore extraction employed here resulted in natural large-scale subsidence. Bethlehem Mines Corporation planned for this effect by purchasing all the surface rights above the mine.

The third site, the St. Joe Minerals Corp. lead mine, was abandoned and sealed in 1973. The galena (PbS) deposit mined here is a typical replacement body in a local dolomite bed. Once again, the alkaline host rock has acted as natural treatment for mine water and maintained pH levels in the 8.3-8.6 range. Water pumped from the mining operations was retained in ponds to allow settling of particulate matter and then released directly to adjacent streams. In all, sixty-two (62) shafts and drifts were sealed using the same closure methods as the above examples. No drainage was observed at the mine openings after sealing. Water levels were measured from observation wells and showed the mine pool stabilizing at 18.3 m (60 ft.) from the surface. This level did not change in the four years that monitoring was conducted, therefore, no drainage problems were expected to develop in this mine district.

Subsidence was encountered due to second and third "robbing" or mining of pillars from the initial room and pillar extraction. Sinks developed at the surface but St. Joe Minerals Corporation was the sole owner of the surface rights so that the area was then fenced-off and posted against trespassing, as a safety measure.

The metal/non-metal industry used the previously described concrete seals for a vast majority of mine closures. These seals have been so effective for obstructing mine openings that many of the Western states have made them mandatory installations for recently abandoned openings. The cost for such seals is approximately $8,500.00* for a typical 6.1 m (20 ft.) x 3.1 m (10 ft.) x 0.9 m (3 ft.) concrete plug.

* Estimated at $125.00/cu. yd. class B cement.

Low costs and longevity of seal life (which reduces maintenance and upkeep costs) present these closures as economically feasible and even desirable under most normal mine closure conditions.

The differences between closure procedures in coal versus metal/non-metal mines is evident. Primary consideration for acid drainage abatement characterizes the coal mining industry and has promoted a surge of technological research in mine seal design. These seals are developed for the purpose of eliminating contact of either air or water with the acid producing materials (pyrite) found in coal and its associated strata. Conversely, the non-coal industry is rarely as concerned with mine drainage as with the personal danger of having open and abandoned mine openings. Since the operator is liable by law for damages to persons or property while on his land or in his mine, it is more of a concern to the mineral mine owner to fence-off and barricade his abandoned workings than it is to abate mine drainage.

TABLE 9. - Index to mine closure case studies.

MINE NAME	SEAM MINED	SEAM QUALITY	OVERBURDEN DESCRIPTION	MINE TYPE	MINING METHOD	WATER QUALITY (Before Closure)	WATER QUALITY (After Closure)	SEAL TYPE	SOURCE OF INFORMATION
Ellisonville Mine		X	X	X			X	X	X
Essex No. 1 Mine	X	X	X	X			X	X	X
Florence Mine		X	X	X			X	X	X
Kelly Mine	X		X	X			X	X	X
McDaniels Mine	X		X	X	X	X	X	X	X
Alben Mine	X		X	X	X	X	X	X	X
Argentine Mine	X	X	X	X				X	X
Becker Mine	X		X	X	X			X	X
Bullrock Run Mine				X		X	X	X	X
Decker No. 5 Mine							X	X	X
Driscoll No. 4 Mine	X			X	X	X	X	X	X
Emery Mine	X		X	X	X	X	X	X	X
Fox Mine*	X		X	X	X	X	X	X	X
Freemont Mine	X		X	X	X	X	X	X	X
Goubeaud Mine	X		X	X	X	X	X	X	X
Hilliard Mine	X	X	X	X	X	X	X	X	X
Isle Mine	X	X	X	X	X	X	X	X	X
Keystone Mine No. 6	X	X	X	X		X	X	X	X
Keystone Mine No. 10	X	X	X	X		X	X	X	X
Keystone Mine No. 19	X	X	X	X		X	X	X	X
Kildoo Mine*	X		X	X	X	X	X	X	X
King No. 2 Mine	X		X	X			X	X	X
Lincoln Mine	X		X	X	X	X	X	X	X

* - Indicates discussion in text

X - Indicates information included in Table 10

TABLE 9. - Index to mine closure case studies - (Cont'd.)

MINE NAME	SEAM MINED	SEAM QUALITY	OVERBURDEN DESCRIPTION	MINE TYPE	MINING METHOD	WATER QUALITY (Before Closure)	WATER QUALITY (After Closure)	SEAL TYPE	SOURCE OF INFORMATION
Lindey Mine *	X	X	X	X	X	X	X	X	X
Martzolf Mine	X		X	X	X	X	X	X	X
Nealy Mine	X		X	X	X	X	X	X	X
North Corridor Mine	X			X	X			X	X
North Goubeauo Mine	X		X	X	X	X	X	X	X
Oneida Mine	X			X				X	X
Preston Mine	X			X	X			X	X
Rattlesnake Creek	X							X	X
Salem No. 2 Mine	X	X	X	X		X	X	X	X
Salzano Ross Mine*	X		X	X	X	X	X	X	X
Shaw Mine*	X	X	X	X		X	X	X	X
Shields Mine	X		X	X	X	X	X	X	X
South Nealy Mine	X		X	X	X	X	X	X	X
Unknown	X	X	X	X	X	X	X	X	X
Unknown	X	X	X	X	X	X	X	X	X
Unknown	X		X	X	X			X	X
West Emery Mine	X		X	X	X	X	X	X	X
Whipkey Mine	X			X	X	X		X	X
Wilmer Mine	X		X	X	X	X	X	X	X
Worth Mine	X		X	X	X	X	X	X	X
Phifers No. 1 Mine	X	X	X	X		X	X	X	X
Banner Mine Complex	X		X	X	X	X		X	X

* - Indicates discussion in text X - Indicates information included in Table 10

TABLE 9. - Index to mine closure case studies - (Cont'd.)

MINE NAME	SEAM MINED	SEAM QUALITY	OVERBURDEN DESCRIPTION	MINE TYPE	MINING METHOD	WATER QUALITY (Before Closure)	WATER QUALITY (After Closure)	SEAL TYPE	SOURCE OF INFORMATION
Coalton #3 RT-5-1	X	X	X	X	X			X	X
Coalton #3 RT-5-2*	X	X	X	X	X			X	X
Coalton #3 RT-5-2A*	X	X	X	X	X	X	X	X	X
Imperial Colliery No. 8 & No. 9	X	X	X	X		X	X	X	X
RT-9-11	X		X	X	X	X	X	X	X
Savage Mine			X	X		X	X	X	X
Stewartstown Mine*	X	X	X	X		X	X	X	X
Big Knob Mines		X	X	X		X	X	X	X
Mine No. 14-042A*	X		X	X	X	X	X	X	X
Mine No. 40-016 #1 & #2*	X	X	X	X	X	X	X	X	X
Mine No. 62-008 #3*	X	X	X	X	X	X	X	X	X
Mine Mo. 62-008 #4*	X	X	X	X	X	X	X	X	X
Mine No. 62-008 #5*	X	X	X	X	X	X	X	X	X
Rock Springs Coalfield	X		X	X	X			X	X
Pennsylvania Composite	X		X	X	X	X	X	X	X

* - Indicates discussion in text

X - Indicates information included in Table 10

TABLE 10. -

STATE	MINE NAME/ REFERENCE	GEOLOGY		TYPE OF OPERATION
		COAL	OVERBURDEN	
Ohio	Ellisonville Mine (Bucek, 1977)	2.6% Sulfur	Calcareous	Drift Mine
	Essex No. 1 Mine (Bucek, 1977)	Middle Kittanning Seam 2.0% Sulfur	Mostly calcareous material and other coal seams.	Drift Mine
	Florence Mine (Bucek, 1977)	2.9% Sulfur	Calcareous	Drift Mine
	Kelly Mine (Bucek, 1977)	Middle Kittanning Seam	Mostly Shale 18m (59') thick	Drift Mine
	McDaniels Mine (Ahmad, N.D.; Bucek, 1977; Harris, 1973; Ohio State University, 1971)	Middle Kittanning Seam 0.45m-0.9m (1.5'-3.0') thick	Sandstone 7.3m-10.7m (24'-35') thick	Drift Mine utilizing the room and pillar method for coal extraction.
Pennsylvania	Alben Mine (Foreman, 1972; Gwin Engineers, Inc., 1968; Foreman and McLean, 1973)	Middle Kittanning Seam .762m-1.016m (30"-40") thick	Sandstone and Shale 3.1-18.3m (10'-60') in depth	Drift Mine utilizing the room and pillar method for coal extraction.
	Argentine Mine (Bucek and Emel, 1977)	Clarion Seam 1 meter (3.28')	33m (108.3') Shale 4m (13') Sandstone 8m (26') Calcareous rock	Drift Mine

Mine closure case studies.

WATER QUALITY		CLOSURE/ SEALING PROCEDURE	REMARKS
BEFORE SEALING	AFTER SEALING		
	Acidity 1,221 mg/l Sulfates 1,020 mg/l Iron 150 mg/l	Cinder Block Wall Air Seal	Location: North of Ironton, Lawrence County, Ohio Mineral Mined: Coal No Pre-Sealing Data Available.
	Acidity 10 mg/l (.27 lbs./d) Sulfates 35 mg/l (.94 lbs./d) Iron 4 mg/l (.11 lbs./d) Flow 8.5 l/m (2.2 g/m)	Dry Seals used in upper elevations of mine. An Air Seal used at lowest elevation so that water may discharge from entry.	Location: Near New Straitsville in the Hocking Valley coalfield Mineral Mined: Coal No Pre Sealing Data Available.
	Acidity 268 mg/l Sulfates 3,050 mg/l Iron 227 mg/l	Cinder Block Wall Air Seal	Location: Belmont County Mineral Mined: Coal No Pre-Sealing Data or Post-Sealing Flow Data Available.
	Acidity 585 mg/l Sulfates 610 mg/l Iron 7 mg/l	Air Seal	Location: Near Ironton, Lawrence County, Ohio Mineral Mined: Coal No Flow Data Available.
Acidity .13 kg/d (.287 lbs./d)	Acidity .09 kg/d (.20 lbs./d)	Single Hydraulic Seal	Location: Northeast of Lake Hope, Vinton County, Ohio Mineral Mined: Coal Mine Has Been Purged With Nitrogen Thus Reducing the Acid Drainage.
Acidity 15.9 kg/d (35 lbs./d) Iron 1.36 kg/d (3 lbs./d) Flow 18.9 l/m (5 g/m)	Acidity 0 kg/d Iron 0 kg/d Flow 0 l/m	Double Bulkhead Hydraulic Seal	Location: Moraine State Park Mineral Mined: Coal Abandoned in 1930. Seals Completed in 1971.
		Double Bulkhead Hydraulic Seal Installed in 1972	Location: Argentine, Pennsylvania Mineral Mined: Coal No Pre- or Post-Sealing Data Available.

TABLE 10. -

STATE	MINE NAME/ REFERENCE	GEOLOGY		TYPE OF OPERATION
		COAL	OVERBURDEN	
Pennsylvania (Cont'd.)	Becker Mine (Foreman, 1972; Gwin Engineers, Inc., 1968; Foreman and McLean, 1973)	Middle Kittanning Seam	Sandstone and Shale 3.1m-60.96m (10'-200') in depth	Drift Mine utilizing the room and pillar method for coal extraction.
	Bullrock Run Mine (Bucek and Emel, 1977)			Drift Mine
	Decker No. 5 (Bucek and Emel, 1977)			
	Driscoll No. 4 (Stoddard, 1973; Michael Baker, Jr., Inc., 1973)	Middle Kittanning Seam 1.37m (4.5') thick		Drift Mine continuous mining method for coal extraction.
	Emery Mine (Foreman, 1972; Foreman and McLean, 1973; Gwin Engineers, Inc., 1968)	Middle Kittanning Seam .76m-1.0m (30"-40") thick	Sandstone and Shale 3.0m-45.7m (10'-150') thick	Drift Mine utilizing the room and pillar method for coal extraction.
	Fox Mine (Foreman, 1972; Foreman and McLean, 1973; Gwin Engineers, Inc., 1968)	Middle Kittanning Seam .76m-1.0m (30"-40") thick, minor folding in seam	Sandstone and Shale 3.0m-45.8m (10'-150') thick	Drift Mine utilizing the room and pillar method for coal extraction.
	Freemont Mine (Foreman, 1972; Foreman and McLean, 1973; Gwin Engineers, Inc., 1968)	Middle Kittanning .76m-1.0m (30"-40") thick	Sandstone and Shale 3.0m-45.7m (10'-150') thick	Drift Mine utilizing the room and pillar method for coal extraction.

Mine closure case studies - (Cont'd.)

WATER QUALITY		CLOSURE/ SEALING PROCEDURE	REMARKS
BEFORE SEALING	AFTER SEALING		
		Double Bulkhead Seal	Location: Moraine State Park Mineral Mined: Coal No Pre- or Post-Sealing Data Available.
Acidity 10 mg/l Sulfates 206 mg/l Iron 16 mg/l	Acidity 27 mg/l (.51-.69 lbs/d) Sulfates 224 mg/l (4.3-5.7 lbs./d) Iron 1 mg/l (.02-.03 lbs./d) Flow 6-8 l/m (1.6-2.1 gal/m)	Single Bulkhead Seal	Location: Kittanning, Pennsylvania A portal for the Mahoning No. 1 Mine sealed in March 1976. No Pre-Sealing Flow Data Available. No Change in pH Before and After Sealing.
	Acidity 49-175 mg/l Sulfate 75-360 mg/l Iron 9-40 mg/l	Two (2) Single Bulkhead Seals over mine entries	Location: Kittanning, Pennsylvania No Pre-Sealing Data or Flow Data Available. Reportedly No Increase in Effluent Quality. pH 1.9-3.2
Acidity 160 mg/l (576.9-769.1 lbs./d) Sulfates 5,000 mg/l (18,027.7-24,034.8 lbs./d) Iron 1,400 mg/l (5,047.7-6,729.7 lbs./d) Flow 1,135.6-1,514 l/m (300-400 g/m)	Acidity 0 mg/l Sulfates 4,500 mg/l (27.1-52.9 lbs./d) Iron 24 mg/l (0.15-.28 lbs./d) Flow 1.9 l/m-3.7 l/m (.5 g/m-1 g/m)	Underground Precipitation Seal	Location: Vintondale, Pennsylvania Mineral Mined: Coal Seal Failed Because of the High Amount of Flow. Abandoned in 1967. Partial Flooding in all Workings of the mine. Plug unstable and Requires Periodic Reestablishing.
Acidity 2.7 kg/d (6 lbs./d) Iron .45 kg/d (1 lb./d) Flow 22.7 l/m (6 g/m)	Acidity 2.7 kg/d (6 lbs./d) Iron No Data Flow 11.36 l/m (3 g/m)	Hydraulic Bulkhead Seal	Location: Moraine State Park Mineral Mined: Coal Mined Closed Since 1930 Seals Installed in 1969.
Acidity 12.7 kg/d (28 lbs./d) Iron 1.4 kg/d (3.1 lbs./d) Flow 53 l/m (14 g/m)	Acidity 0.45 kg/d (1 lb./d) Iron No Data Flow 11.4 l/m (3 g/m)	Hydraulic Seals	Location: Moraine State Park Mineral Mined: Coal Abandoned in 1930, Sealed June, 1970.
Acidity .45 kg/d (1 lb./d) Iron <.45 kg/d (<1 lb./d) Flow 3.78 l/m (1 g/d)	Acidity <.45 kg/d Iron <.45 kg/d Flow 7.57 l/m (2 g/m)	Hydraulic Double Bulkhead Seal	Location: Moraine State Park Mineral Mined: Coal Abandoned in 1930. Mine is Partially Flooded.

TABLE 10. -

STATE	MINE NAME/ REFERENCE	GEOLOGY		TYPE OF OPERATION
		COAL	OVERBURDEN	
Pennsylvania (Cont'd.)	Goubeaud Mine (Foreman, 1972; Foreman and McLean, 1973; Gwin Engineers, Inc., 1968)	Middle Kittanning Seam .76m-1.0m (30"-40") thick	Sandstone and Shale 3.0m-30.5m (10'-100') thick	Drift Mine utilizing the room and pillar method for coal extraction.
	Hilliard Mine (Foreman, 1972; Foreman and McLean, 1973; Gwin Engineers, Inc., 1968)	Middle Kittanning Seam Minor folds are present Within the Seam. .88m (2.9') thick and 2.8% sulfur	Sandstone, Shale, Coal and Limestone 3.0m-30.5m (10'-100') thick	Drift Mine utilizing the room and pillar method for coal extraction.
	Isle Mine (Foreman, 1972; Gwin Engineers, Inc., 1968; Bucek and Emel, 1977; Foreman and McLean, 1973)	Middle Kittanning Seam .76m-1.0m (30"-40") thick. Minor folds are present in seam. 2.8% sulfur	Sandstone, Shale, Coal and Some Limestone 3.0m-88.4m (10'-290') thick	Drift Mine utilizing the room and pillar method for coal extraction.
	Keystone No. 6 Mine Keystone No. 10 Mine Keystone No. 19 Mine (Bucek and Emel, 1977)	Clarion Seam 1m (39.4") thick 2.7% sulfur	Mostly Shale With Sandstone Approximately 3.5m (11.4') and Calcareous Rocks and Coal Averaging 9m (29.5') in Thickness. At Mine No. 10, Thickness of Overburden is About 44m (144'), While at Mine No. 19, Overburden Thickness Averages at About 29 Meters (95').	Drift Mines

Mine closure case studies - (Cont'd.)

WATER QUALITY		CLOSURE/ SEALING PROCEDURE	REMARKS
BEFORE SEALING	AFTER SEALING		
Acidity .91 kg/d (2 lbs./d) Iron <.45 kg/d (1 lb./d) Flow 7.6 l/m (2 g/m)	Acidity 0 kg/d Iron 0 kg/d Flow 0 l/m	Hydraulic Double Bulkhead Seal	Location: Moraine State Park Mineral Mined: Coal Mine Abandoned in the 1930's. Seal Installed in August, 1968.
Acidity 2.7 kg/d (6 lbs./d) Iron <.45 kg/d (<1 lb./d) Flow 41.6 l/m (11 g/m)	Acidity 1.8 kg/d (4 lbs./d) Iron <.45 kg/d (<1 lb./d) Flow 15.1 l/m (4 g/m)	Hydraulic Double Bulkhead Seal and also Blockhead Seal with a 300m (984') grout curtain	Location: Moraine State Park Mineral Mined: Coal Abandoned in the 1930's. Mine is Partially or Completely Inundated. Sealed June, 1970.
Acidity .91 kg/d (2.0 lbs./d) Iron .45 kg/d (.99 lbs./d) Flow 22.7 l/d (6 g/d)	Acidity 0 kg/d Iron 0 kg/d Flow 0 l/d	Hydraulic Double Bulkhead Seals	Location: Moraine State Park Mineral Mined: Coal Abandoned in the 1930's. Six (6) Entries were Sealed. Work Completed in November, 1969. Seal Leakage Present Where Seal is in Contact with the Mine Floor.
Acidity No. 6 Mine 104 mg/l Iron 5 mg/l Sulfates 381 mg/l Acidity No. 10 Mine .46 kg/d (1.01 lbs./d) Iron No Data Alkalinity .12 kg/d (.26 lbs./d) Flow 20 l/m (5.3 g/m) Acidity No. 19 Mine 3.7 kg/d (8.2 lbs./d) Iron No Data Alkalinity 0 mg/l Sulfates 13.1 kg/d (28.9 lbs./d) Flow 25 l/m (6.6 g/m)	Acidity No. 6 Mine 0 mg/l Iron 0 mg/l Sulfates 0 mg/l Flow 0 l/m Acidity No. 10 Mine .99 kg/d (2.18 lbs./d) Iron No Data Alkalinity 27.5 kg/d (60.6 lbs./d) Flow 115 l/m (30.4 g/m) Acidity No. 19 Mine .01 kg/d (.02 lbs./d) Iron No Data Alkalinity .01 kg/d (.02 lbs./d) Sulfates .04 kg/d (.08 lbs./d) Flow 1 l/m (.26 g/m)	Hydraulic Double Bulkhead Seals	Location: Boyers, Pennsylvania. All Three (3) Mines are Interconnected. Mineral Mined: Coal Production During the Late 1800's - Early 1900's. All Mine Sections were Hydraulically Sealed in June, 1975. Seal on Mine No. 6 Completely Obstructs all Discharge Flow. It is Believed Flow Increased in No. 10 Because of the Seals Over Mine No. 6 and Mine No. 19.

TABLE 10. -

STATE	MINE NAME/ REFERENCE	GEOLOGY		TYPE OF OPERATION
		COAL	OVERBURDEN	
Pennsylvania (Cont'd.)	Kildoo Mine (Gwin Engineers, Inc., 1968; Foreman, 1972; Foreman and McLean, 1973)	Middle Kittanning Seam .76m-1.0m (30"-40") thick. Minor folding present within the seam.	Sandstone, Shale, Coal, Limestone 3.0m-61m (10'-200') thick	Drift Mine utilizing the room and pillar method for coal extraction.
	King No. 2 Mine (Robins, 1973)	Lower Kittanning Seam .91m (36") thick	Varies in depth to a maximum of 52m (171') thick	Drift Mine
	Lincoln Mine (Foreman, 1972; Gwin Engineers, Inc., 1968; Foreman and McLean, 1973)	Middle Kittanning Seam	Sandstone, Shale, Coal 3.0m-30.5m (10'-100') thick	Drift Mine utilizing the room and pillar method for coal extraction.
	Lindey Mine (Foreman, 1972; Foreman and McLean, 1973; Bucek and Emel, 1977)	Middle Kittanning Seam .76-1.0m (30"-40") thick 2.8% sulfur	Sandstone, Shale, Coal, Limestone 3m-36.6m (10'-120') thick	Drift Mine utilizing the room and pillar method for coal extraction.
	Martzolf Mine (Foreman, 1972; Gwin Engineers, Inc., 1968; Foreman and McLean, 1973)	Middle Kittanning Seam .76m-1.0m (30"-40") thick	Sandstone, Shale, Coal, Small Beds of Limestone 3.0m-76.2m (10'-250') thick	Drift Mine utilizing the room and pillar method for coal extraction.
	Nealy Mine (Foreman, 1972; Gwin Engineers, Inc., 1968; Foreman and McLean, 1973)	Middle Kittanning Seam .76m-1.0m (30"-40") thick	Sandstone, Shale, Coal, Limestone 3.0m-51.8m (10'-170') thick	Drift Mine utilizing the room and pillar method for coal extraction.
	North Corridor Mines (Gwin Engineers, Inc., 1968; Foreman and McLean, 1973)	Middle Kittanning Seam .76m-1.0m (30"-40") thick		Drift Mine utilizing the room and pillar method for coal extraction.

Mine closure case studies - (Cont'd.)

WATER QUALITY		CLOSURE/ SEALING PROCEDURE	REMARKS
BEFORE SEALING	AFTER SEALING		
Acidity 46.3 kg/d (102 lbs./d) Iron 3.64 kg/d (8 lbs./d) Flow 94.6 l/m (25 g/m)	Acidity 13.6 kg/d (30 lbs./d) Iron 3.2 kg/d (7 lbs./d) Flow 36.8 l/m (9.7 g/m)	Hydraulic Bulkhead Seals	Location: Moraine State Park Mineral Mined: Coal Abandoned in 1930's. Sealing Completed in November of 1970 with One (1) Seal Over Each of the Four (4) Different Entries.
No Data Available	Acidity 42.9 kg/d (94.6 lbs./d) Iron 1.96 kg/d (4.3 lbs./d) Flow 37.85 l/m (10 g/m)	Three (3) Concrete Block Seals were used in the upper entries and two (2) Air Seals were installed in the lower entries of the mine.	Location: Steward Township, Fayette County, Pennsylvania Mineral Mined: Coal Seal Completed in 1964.
Acidity 49 kg/d (108 lbs./d) Iron 2.3 kg/d (5 lbs./d) Flow 75.7 l/m (20 g/m)	Acidity 31.7 kg/d (70 lbs./d) Iron 10.4 kg/d (23 lbs./d) Flow 34.1 l/m (9 g/m)	Four (4) entries sealed using Double Bulkhead Seals	Location: Moraine State Park Mineral Mined: Coal Abandoned in the 1930's. Mine Sealed October 1970. 609.6m (2,000') of Grout Curtain was Also Used to Support the Seal.
Acidity 8.2 kg/d (18 lbs./d) Iron .91 kg/d (2 lbs./d) Flow 18.9 l/m (5 g/m)	Acidity 5.4 kg/d (12 lbs./d) Iron 2.7 kg/d (6 lbs./d) Flow 18.9 l/m (5 g/m)	Five (5) Hydraulic Double Bulkhead Seals were placed over the mine entries.	Location: Moraine State Park Mineral Mined: Coal Abandoned in the 1930's. Sealing Completed August, 1970.
Acidity .90 kg/d (2 lbs./d) Iron .45 kg/d (1 lb./d) Flow 15.4 l/m (4 g/m)	Acidity 0 kg/d Iron 0 kg/d Flow 0 l/d	Two (2) Hydraulic Double Bulkhead Seals over each mine entry.	Location: Moraine State Park Mineral Mined: Coal Abandoned in 1930's. Mine Seal Completed in 1969.
Acidity 1.8 kg/d (4 lbs./d) Iron <.45 kg/d (1 lb./d) Flow 18.9 l/m (5 g/m)	Acidity 0 kg/d Iron 0 kg/d Flow 0 l/m	Double Bulkhead Seals are used in six drift openings. Seals were made up of concrete blocks or clay in areas without a drainage problem.	Location: Moraine State Park Mineral Mined: Coal Abandoned in 1930's. All Seals Completed in August, 1969.
		Double Bulkhead Seals on the four (4) mine entries.	Location: Moraine State Park Mineral Mined: Coal Abandoned in 1930.

TABLE 10. -

STATE	MINE NAME/ REFERENCE	GEOLOGY		TYPE OF OPERATION
		COAL	OVERBURDEN	
Pennsylvania (Cont'd.)	North Goubeaud Mine (Foreman, 1972; Gwin Engineers, Inc., 1968; Foreman and McLean, 1973)	Middle Kittanning Seam .76m-1.0m (30"-40") thick. Minor folding present.	Sandstone, Shale, Thin Coal Seam and Possibly Limestone 3.0m-31m (10'-100') thick	Drift Mine utilizing the room and pillar method for coal extraction.
	Oneida Mine (Braley, 1962)	Lower Kittanning Seam 1.2m-1.5m (4'-5') thick		Drift Mine
	Preston Mine (Gwin Engineers, Inc., 1968; Foreman and McLean, 1973)	Middle Kittanning Seam .76m-1.0m (30"-40") thick		Drift Mine utilizing the room and pillar method for coal extraction.
	Rattlesnake Creek Mine (Bucek and Emel, 1977)	Lower Kittanning Seam .89m (35") coal .20m (8") parting .38m (15") coal		
	Salem No. 2 Mine (Bucek and Emel, 1977; Chung, 1973)	Middle Kittanning Seam 1.3m (4.3') thick 1.7% sulfur	Shale and Sandstone 9.1m (30') thick	Drift Mine
	Salzano Ross Mine (Foreman, 1972; Gwin Engineers, Inc., 1968)	Middle Kittanning Seam	Sandstone, Shale, Coal, and Possible Limestone 3m-51.8m (10'-170') thick	Drift Mine utilizing the room and pillar method for coal extraction.
	Shaw Mine (Bucek and Emel, 1977)	Pittsburgh and Redstone Seams 1.7% sulfur	30m (98.4') Predominantly shale	Slope/Shaft

Mine closure case studies - (Cont'd.)

WATER QUALITY		CLOSURE/ SEALING PROCEDURE	REMARKS
BEFORE SEALING	AFTER SEALING		
Acidity <.45 kg/d (<1 lb./d) Iron <.45 kg/d (<1 lb./d) Flow 303 l/m (8.0 g/m)	Acidity 0 kg/d Iron 0 kg/d Flow 0 l/m	One (1) Double Bulkhead Seal installed at all three (3) mine entries.	Location: Moraine State Park Mineral Mined: Coal Abandoned in 1930. Seal Completed in September, 1969.
		Air Seal	Location: Near Indian Head, Pennsylvania Mineral Mined: Coal Water Quality not Improved After the Seal Installation.
		Double Bulkhead Seal placed at all three (3) mine entrances.	Location: Moraine State Park Mineral Mined: Coal
		Single Bulkhead	Location: Brockway, Jefferson County, Pennsylvania Mineral Mined: Coal
Acidity 162.3 kg/d (358 lbs./d)	Acidity 3.5 kg/d (7.7 lbs./d)	Vinyl Polymer Seal or "Gel Seal"	Location: Keystone State Park Mineral Mined: Coal Seal Failed Because Flow in Mine was too Great to enable the Grout to Form the Gel Seal; therefore, Washing Out the Seal. After Seal Installation: Acidity Reduced by 32%; Sulfates Reduced by 48%; Iron Reduced by 4%.
Acidity 66.7 kg/d (147 lbs./d) Iron 1.8 kg/d (4 lbs./d) Flow 37.9 l/m (10 g/m)	Acidity 5.9 kg/d (13 lbs./d) Iron 1.8 kg/d (4 lbs./d) Flow 18.9 l/m (5 g/d)	Air Seals and Double Bulkhead Seal were used to seal the mine.	Location: Moraine State Park Mineral Mined: Coal Mine Closed in 1966. Air Seal Used in 1967, Replaced in 1969 by a Double Bulkhead Seal to Improve the Water Quality of Re-Discharge.
Acidity 1,505 mg/l Iron 459 mg/l Sulfates 2,915 mg/l	Acidity 993.3 mg/l Iron 275.4 mg/l Sulfates 1,574.1 mg/l	Pressure grouted coarse aggregate with plug filled with concrete. A grout curtain was placed against the plug to secure the water tightness of the seal.	Location: Myersdale, Pennsylvania Mineral Mined: Coal No Flow Data Available.

TABLE 10. -

STATE	MINE NAME/ REFERENCE	GEOLOGY		TYPE OF OPERATION
		COAL	OVERBURDEN	
Pennsylvania (Cont'd.)	Shields Mine (Foreman, 1972; Foreman and McLean, 1973; Gwin Engineers, Inc., 1968)	Middle Kittanning Seam	3m-30.5m (10'-100') thick	Drift Mine utilizing the room and pillar method for coal extraction.
	South Nealy Mine (Foreman, 1972; Foreman and McLean, 1973; Gwin Engineers, Inc., 1968)	Middle Kittanning Seam .76m-1.0m (30"-40")	Sandstone, Shale, Coal, and Limestone 3m-36.6m (10'-120')	Drift Mine utilizing the room and pillar method for coal extraction.
	Unknown (Chamberlian, 1972)	Pittsburgh Seam 2.3m (92") thick 2.6% pyrite	Ranges from 6.1m-109.7m (20'-360')	Drift Mine utilizing the room and pillar method for coal extraction.
	Unknown (Krickovic and Moebs, 1970)	Upper Freeport Seam 1.1m (3.5') thick .19-50% sulfur	35m (115') Siltstone with 3m (10') interbeds of sandstone. 5.2m (17') thinly interbedded siltstone and sandstone.	Drift Mine utilizing a modified room and pillar method for continuous coal extraction.
	Unknown (Gwin Engineers, Inc., 1968; Foreman and McLean, 1973)	Middle Kittanning Seam .76m-1.0m (30"-40") thick	Sandstone, Shale, Coal, and thin beds of Limestone 3.0m-30.5m (10'-100') thick	Drift Mine utilizing the room and pillar method for coal extraction.
	West Emery Mine (Foreman, 1972; Gwin Engineers, Inc., 1968; Foreman and McLean, 1973)	Middle Kittanning Seam .76m 1.0m (30" 40") thick. Minor folding present.	Sandstone and Shale 3m-30.5m (10'-100')	Drift Mine utilizing the room and pillar method for coal extraction.
	Whipkey Mine (Robins, 1973)	Lower Kittanning Seam .91m (36") thick		Drift Mine utilizing the room and pillar method for continuous coal extraction.

Mine closure case studies - (Cont'd.)

WATER QUALITY		CLOSURE/ SEALING PROCEDURE	REMARKS
BEFORE SEALING	AFTER SEALING		
Acidity <.45 kg/d (<1 lb./d) Iron <.45 kg/d (< 1 lb./d) Flow <3.7 l/m (< 1 g/m)	Acidity <.45 kg/d (< 1 lb./d) Iron <.45 kg/d (< 1 lb./d) Flow < 3.7 l/m (< 1 g/d)	A Double Bulkhead Seal was installed at each of the five (5) individual mine entries.	Location: Moraine State Park Mineral Mined: Coal Mine Closed 1930. Seal Construction Completed in 1970.
Acidity 1.4 kg/d (3 lbs./d) Iron .45 kg/d (1 lb./d) Flow 7.6 l/m (2 g/m)	Acidity 0 kg/d Iron 0 kg/d Flow 0 l/m	Double Bulkhead Seals used on mine entries.	Location: Moraine State Park Mineral Mined: Coal Abandoned in 1930. Two (2) Entries Sealed in June 1969.
Acidity 0 mg/l Iron 66 mg/l Sulfates 2,137 mg/l	Acidity 5 mg/l Iron 70 mg/l Sulfates 1,661 mg/l	All mine entries sealed with a Single Bulkhead Seal.	Location: Twenty-Seven Miles South of Pittsburgh, Pennsylvania Mineral Mined: Coal Mine Closed in 1968. No Flow Data Available.
Acidity 514 mg/l Iron 160 mg/l Sulfates 1,403 mg/l	Acidity 211 mg/l Iron 62 mg/l Sulfates 874 mg/l	Eight (8) separate seals were incorporated in closing this mine; one (1) wet, and seven (7) Dry Seals.	Location: Forty (40) Miles Northeast of Pittsburgh, Pennsylvania Mineral Mined: Coal Mining Activity Ceased in 1959. Mine Seals Completed in April, 1968. No Flow Data Available.
		Double Bulkhead Seal	Location: Moraine State Park Mineral Mined: Coal
Acidity .91 kg/d (2 lbs./d) Iron .45 kg/d (1 lb./d) Flow 15 l/m (4 g/m)	Acidity .91 kg/d (2 lbs./d) Iron <.45 kg/d (< 1 lb./d) Flow 11.4 l/m (3 g/m)	Double Bulkhead Seal used at all three (3) mine entries.	Location: Moraine State Park Mineral Mined: Coal Abandoned in 1930. Mine Seal Completed in 1969.
Acidity 750 mg/l (180 lbs./d) Flow 75.7 l/m (20 g/m)	Acidity No Data Available Flow No Data Available	Dry Seals used with the intent of filling mine with inert gas to stop acid production.	Location: Stewart Township, Fayette County, Pennsylvania Mineral Mined: Coal Mining Activity Ceased in 1964.

TABLE 10. -

STATE	MINE NAME/ REFERENCE	GEOLOGY		TYPE OF OPERATION
		COAL	OVERBURDEN	
Pennsylvania (Cont'd.)	Wilmer Mine (Gwin Engineers, Inc., 1968; Foreman and McLean, 1973)	Middle Kittanning Seam .76m-1.0m (30"-110") thick	Sandstone and Shale 3.0m-18.3m (10'-60') thick	Drift Mine utilizing the room and pillar method for coal extraction.
	Worth Mine (Foreman, 1972; Gwin Engineers, Inc., 1968; Foreman and McLean, 1973)	Middle Kittanning Seam .76m-10m (30"-40") thick	Sandstone and Shale 3.0m-24.4m (10'-80') thick	Drift Mine utilizing the room and pillar method for coal extraction.
Tennessee	Phifers No. 1 Mine (Bucek, 1977)	Richland Seam 1.5m (4.9') thick 2.2% sulfur	Thin Shale No coal or calcareous rock.	Drift Mine
West Virginia	Banner Mine Complex: Corinth-Lima Area Turner-Douglass Area Freeport-Laurel Run Area Banner Mine Area Ashby Pendergast Mine Area (Baker-Wibberley and Associates, Inc., 1977)	Lower Kittanning Seam 3m (10') thick	Cyclic sequences of shale, sandstone coal and underclay	Drift Mine utilizing the room and pillar method for coal extraction.
	Coalton #3 RT-5-1 RT-5-2 RT-5-2A (U.S. EPA, 1977; Halliburton Company, 1970; Bucek and Emel, 1977)	Lower Kittanning Seam 2.4m (8') thick with 2% sulfur content	Shaley-Limestone 6.2m (20') siltstone 6.2m (20') silty sandstone 4.6m (15') sandy shale 1.5m (5') carboniferous shale 4.3m (14')	Drift Mine with continuous and longwall methods used for coal extraction.

Mine closure case studies - (Cont'd.)

WATER QUALITY		CLOSURE/ SEALING PROCEDURE	REMARKS
BEFORE SEALING	AFTER SEALING		
Acidity 15.9 kg/d (35 lbs./d) Iron 1.8 kg/d (4 lbs./d) Flow 68 l/m (18 g/m)	Acidity 10 kg/d (22 lbs./d) Iron .90 kg/d (2 lbs./d) Flow 30.3 l/m (8 g/m)	Hydraulic Double Bulkhead Seal. One over each of the three (3) mine entries.	Location: Moraine State Park Mineral Mined: Coal Operation Closed in 1930. Seals Completed in 1970.
Acidity 0 kg/d Iron 0 kg/d Flow 0 l/m	Acidity 0 kg/d Iron 0 kg/d Flow 0 l/m	Double Bulkhead Seal at each of the three (3) entries.	Location: Moraine State Park Mineral Mined: Coal Abandoned in 1930. Seals Completed in 1971.
Acidity 83 mg/l (2.9 lbs./d) Sulfates 109 mg/l (3.8 lbs./d) Iron 14 mg/l (.5 lbs./d) Flow 11 l/m (2.9 g/m)	Acidity 0 mg/l Sulfates 48 mg/l Iron 9.8 mg/l Flow 0 l/m	Double Bulkhead Seal (Limestone aggregate, grouted with a cement mix)	Location: Near State Park, Tennessee Mineral Mined: Coal Mine Sealed November, 1975.
Acidity 450 mg/l Sulfates 550 mg/l Iron 62 mg/l pH 2.6	No Data at This Time.	Continuous clay dams around the crop and in adjacent streams, will form level control lake which inundates all workings. A single concrete bulkhead will be installed at the Asby Pendergast Mine with some success.	Location: 700m (0.4 mi.) southwest of Corinth, West Virginia, near border of Preston County, West Virginia and Garrett County, Maryland Mineral Mined: Coal The Sealing Process was Initiated in 1977-1978 and is not Completed at the Present Time.
RT-5-2A Acidity 365.8 kg/d (806 lbs./d) Sulfates 472.1 kg/d (1,041 lbs./d) Iron 125.8 kg/d (277 lbs./d) Flow 5.4 l/m (85 g/m) pH 2.9	RT-5-2A Acidity 2.9 kg/d (6.4 lbs./d) Sulfates 18.0 kg/d (40 lbs./d) Iron 2.8 kg/d (6.2 lbs./d) Flow .31 l/m (4.9 g/m) pH 5.7	Mines RT-5-1 & 2 Sealed with a Double Bulkhead Seal Mine RT-5-2A Permeable limestone plug 9.2m (30') long	Location: Coalton, West Virginia in the Elkins Project Area Mineral Mined: Coal Openings Were Sealed in 1969 by Halliburton Company. Seals (On Portals) 1 and 2 Were Constructed and Did Not Leak. Seal on Portal #2A was Constructed of Permeable Limestone Aggregate in Order to Treat Drainage and Allow a Regulated Flow.

TABLE 10. -

STATE	MINE NAME/ REFERENCE	GEOLOGY		TYPE OF OPERATION
		COAL	OVERBURDEN	
West Virginia (Cont'd.)	Imperial Colliery Nos. 8 and 9 (Bucek and Emel, 1977)	No. 2 Gas Coal 0.9% Sulfur	Overburden 164m (533') Shale 98m (320') Sandstone 66m (213')	Drift Mines
	RT-9-11 (U.S. EPA, 1977; Bucek and Emel, 1977; Michael Baker, Jr., Inc., 1973)	Lower Kittanning Seam Max. 3m (9.8') thick	Sandstone 18m (59') Shale 18m (59')	Small drift mine about 0.2 km^2 (50 ac.) utilizing room and pillar mining method with pillar robbing upon retreat.
	Savage Mine (U.S. EPA, 1977; Bucek and Emel, 1977)		Shale 23m (75') Sandstone 20m (65')	Small Drift Mine approximately 0.33km^2 (81.5 ac.)
	Stewartstown Mine (Bucek and Emel, 1977)	Coal is 0.9m (2.9') thick with about 3.1% sulfur.	Overburden averages 34m (110') thick with a predominance of shale over sandstone.	Drift Mine 0.1 km^2 (25 ac.)
	Big Knob Mines Portals #1, 2 and 6 (U.S. EPA, 1977; Bucek and Emel, 1977)	Coal seam contains 0.6% sulfur	Shale 23m (75') Sandstone 20m (65')	Drift Mine approximately 0.22 km^2 (54.4 ac.)

Mine closure case studies - (Cont'd.)

WATER QUALITY		CLOSURE/ SEALING PROCEDURE	REMARKS
BEFORE SEALING	AFTER SEALING		
Acidity 68 mg/l Sulfates 705 mg/l Iron 2 mg/l pH 6.1	1 year after closure Acidity 290 mg/l Sulfates 557 mg/l Iron 16 mg/l pH 6.1	Mine No. 8 sealed with an earth seal. Mine No. 9 sealed with an air seal.	Location: Burnwell, West Virginia Mineral Mined: Coal Openings Were Sealed in 1972. Very Little Water Quality Data Available but After Initial Deterioration, a Continuous Improvement Trend in Quality Has Been Noticed.
Acidity 591 mg/l Sulfates 1,035 mg/l Iron 93 mg/l pH 2.8	Acidity 326 mg/l Sulfates 535 mg/l Iron 73 mg/l pH 3.0	Air Seals were installed in all openings.	Location: Near Pumpkintown, West Virginia Mineral Mined: Coal Mine Sealed in 1967. All Pollutant Parameters had Shown Signs of Some Improvement Except for Rate of Flow.
Acidity 24 mg/l Sulfates 36 mg/l Iron .05 mg/l	Acidity 12 mg/l Sulfates 2 mg/l Iron 2 mg/l	Two (2) seals; 1966 - 1 wet, 1 dry. Cement Block-Type Seals.	Location: Near Bowden, West Virginia Mine Sealed in 1966, but West Virginia Department of Mines Due to Fishkill at Bowden Hatchery.
Acidity 22.0 kg/d (48.5 lbs./d) Sulfates 51.4 kg/d (113 lbs./d) Iron 4.2 kg/d (9.3 lbs./d) pH 3.0	Acidity 2.3 kg/d (5 lbs./d) Sulfates 10.6 kg/d (23 lbs.) Iron 0.4 kg/d (.9 lbs./d) pH 6.8	Four (4) Permeable Seals with grout curtains were installed. Additional grouting was performed at the roof contact of each seal. One (1) seal (No. 2) leaked by 1976.	Location: Near Stewartstown, West Virginia Mineral Mined: Coal Closed in 1974 by ECI-Doletanche, Inc. Mine Closed in 1974. Seal failed in 1976.
No. 2 Portal Acidity 2.1 kg/d (4.6 lbs./d)	Acidity 1.2 kg/d (2.6 lbs./d)	Portals #1-6 — Cement Block, Single Bulkhead Seals or "Wet Seals"	Location: Near Bowden, West Virginia Mineral Mined: Coal One of Several Mines Sealed Due to Fishkill at Bowden Hatchery on Shavers' Fork. No Significant Change in Pollutant Parameters Other Than in Acidity Discharge.

TABLE 10. -

STATE	MINE NAME/ REFERENCE	GEOLOGY		TYPE OF OPERATION
		COAL	OVERBURDEN	
West Virginia (Cont'd.)	Mine #14-042A (Halliburton Company, 1970; Bucek and Emel, 1977; Halliburton Company, 1968)	Pittsburgh Seam 2.4m (8') thick	Sandstone and Shale 3.0m-18.3m (10'-60')	Drift Mine utilizing the room and pillar method for coal extraction.
	Mine #40-016 (Halliburton Company, 1970; Bucek and Emel, 1977)	Redstone and Pittsburgh Seams 1.8m-2.2m (6-7') thick. 3% sulfur	Shale 1.8m (6') Sandstone 3.1m (10') Limestone 0.9m (3') Shale 3.1m (10') Slate 0.5m (1.5')	Drift Mine utilizing the room and pillar method for coal extraction.
	Mine #62-008 (Halliburton Company, 1970; Bucek and Emel, 1977)	Pittsburgh Seam 2.1m (7') 3.1% sulfur	Shale 1.8m (6') Sandstone 3.0m (10') Limestone 0.9m (3') Shale 3.0m (10') Slate 0.5m (1.5')	Drift Mines utilizing room and pillar mining with pillar robbing upon retreat.

Mine closure case studies - (Cont'd.)

WATER QUALITY		CLOSURE/ SEALING PROCEDURE	REMARKS
BEFORE SEALING	AFTER SEALING		
Acidity 2,750 mg/l Sulfates 0 Iron 558 mg/l (116.9 lbs./d) Flow 1.1 l/s (17.4 g/m) pH 2.6	Acidity 2,475 mg/d (47 lbs./d) Sulfates 3,440 mg/l (66 lbs./d) Iron 476 mg/l (9.1 lbs./d) Flow 0.1 l/s (1.6 g/m) pH 2.6	Expandable Grout Bag Seal with remedial pressure grouting.	Location: One (1) Mile South of Clarksburg, West Virginia Mineral Mined: Coal Seal Installed in 1967.
Openings #1 and #2 Acidity 351 mg/l (635 lbs./d) Iron 155 mg/l (280.5 lbs./d) Flow 9.5 l/s (150.6 g/m) pH 2.9-3.4	Opening #1 Acidity 325 mg/l (24.8 lbs./d) Iron 132 mg/l (10 lbs./d) Flow 0.4 l/s (6.3 g/m) pH 3.5 Opening #2 Acidity 163 mg/l (12.4 lbs./d) Iron 52 mg/l (4 lbs./d) Flow 0.4 l/s (6.3 g/m) pH 6.5	Two (2) openings were cleared and cleaned and two (2) Limestone Aggregate Seals were installed.	Location: South of Clarksburg, West Virginia, between West Milford and Lost Creek. Mineral Mined: Coal Mine Sealed in 1969.
Opening #3 Acidity 200 mg/l (7.6 lbs./d) Sulfates 2,220 mg/l (84.6 lbs./d) Iron 55 mg/l (2.1 lbs./d) Flow 0.2 l/s (3.2 g/m)	Opening #3 Acidity 111 mg/l (4.2 lbs./d) Sulfates 2,441 mg/l (93 lbs./d) Iron 45 mg/l (1.7 lbs./d) Flow .2 l/s (3.2 g/m)	#3 Limestone Aggregate Plug #4 Single Bulkhead #5 Double Bulkhead	Location: Three (3) Miles West of Lost Creek, Harrison County, West Virginia Three (3) Seals in Openings #3, #4, and #5. Sealing Complete in 1975.
Opening #4 Acidity 459 mg/l (26.2 lbs./d) Iron 119 mg/l (6.8 lbs./d) Flow .3 l/s (4.8 g/m)	Opening #4 Acidity 44.6 mg/l (.17 lbs./d) Iron 16 mg/l (.06 lbs./d) Flow .02 l/s (0.32 g/m)		
Opening #5 Acidity 2,260 mg/l (387.5 lbs./d) Iron 555 mg/l (95.2 lbs./d) Flow 0.9 l/s (14.3 g/m) pH 2.8	Opening #5 Acidity 1,090 mg/l (2.1 lbs./d) Iron 483 mg/l (.92 lbs./d) Flow 0.01 l/s (0.2 g/m) pH 2.8		

TABLE 10. -

STATE	MINE NAME/ REFERENCE	GEOLOGY		TYPE OF OPERATION
		COAL	OVERBURDEN	
Wyoming	Rock Springs Coalfield, Wyoming (Allen, A.S., et. al., 1975; Candeub, Flessig, and Associates, 1973)	Four (4) coalbeds, superposed at random — 1.8m (6') average thickness each bed, with a maximum aggregate thickness of 27.4m (90')	Rock Springs formation of Cretaceous Age Depth to bedrock 1.8m to 15.8m (6'-52') - silty alluvium with thin underclay. Generally repetitive sequence of coalbeds, carbonaceous shales, siltstone, claystone, and sandstone.	Mine utilizing the room and pillar method for coal extraction.
Pennsylvania	Northern Anthracite Field (Allen, A.S. and R.H. Whaite, 1975; Ash, S.H., 1954)	Big Bed 3.0m (10') thick New County Bed 1.8m (6') thick Clark Bed 2.4m (8') thick Dunmore Bed	Rock cover 1.2m-10.1m (4'-33') thick	Deep Mine utilizing the room and pillar method for continuous coal extraction.
	Pennsylvania Anthracite Area (Ash, S.H., 1941; W.L. Eaton, K. Hughes, W.M. Romischek, 1949; Felegy, E.W., L.H. Johnson, J. Westfield, 1948; Berger Associates and A.B. Riedel Associates, 1975)	Northern Field Lackawanna Syncline Eastern Middle Field Anticlines and Synclines Southern Field intensely folded Western Middle Field folded into a series of alternating Synclines and Anticline		Slope and Drift Mines utilizing the room and pillar method for coal extraction.
	Unknown (Doyle, Wm. S. 1976; Michael Baker, Jr., Inc., 1973; Moebs, N.N. and S. Krickovic, 1970)			Drift Mine approximately 77 acres.

Mine closure case studies - (Cont'd.)

WATER QUALITY		CLOSURE/ SEALING PROCEDURE	REMARKS
BEFORE SEALING	AFTER SEALING		
		Pumped Slurry Technique	Location: Southwest Corner of Wyoming. Mineral Mined: Coal This Project was Undertaken to Evaluate the Effects, on Surface Subsidence, of Pumping a Blind Slurry of Water and Sand into a Portion of an Underground Mine using a New Hydraulic Method. It was Determined by the Investigating Agency that the New Method was Feasible. Subsidence Occurring in Areas Over Mines Closed 35 to 50 Years Ago.
		Bulkhead Seals	Location: Green Ridge Area of Lackawanna County Mineral Mined: Coal All Workings Inundated in McClark Bed.
		Double Bulkhead Seals	Location: Eastern and Northeastern Pennsylvania Mineral Mined: Coal Mine in Operation from 1870's - present.
Acidity 514 mg/l Sulfates 1,403 mg/l Iron 160 mg/l	Acidity 211 mg/l Sulfates 874 mg/l Iron 62 mg/l	1 Air Seal 7 Dry Seals	Location: Forty (40) Miles Northeast of Pittsburgh, Pennsylvania Sealing Completed in May, 1966.

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APPENDIX A - LIST OF CONTACTS

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
Alabama						
James R. Boyle U.S. Bureau of Mines University, Alabama 205-758-0491	X	X			X	
Rusty Williams Alabama Safety and Inspection 205-251-1181	X	X	X			
William Gibson Alabama Water Improvement Commission 205-277-3630	X	X	X			
Alaska						
Alfred Service U.S. Bureau of Mines Anchorage, Alaska 907-265-4304		X	X		X	
Pete Nelson Alaska 907-263-2257		X				X
Arkansas						
Roy Brown State Mine Inspector Fort Smith, Arkansas 501-452-5125		X	X		X	
Milt Bonner Department of Pollution Control and Ecology Little Rock, Arkansas 501-371-1701		X				X
Charles Daniels Arkansas Labor Commissioner 501-378-5965		X				

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Arkansas (Cont'd.)						
Floyd Durham Department of Pollution Control and Ecology Little Rock, Arkansas 501-371-1701		X	X		X	
William Richty Raymond Stroud U.S. Bureau of Mines Little Rock, Arkansas 501-378-5965		X			X X	
William Bush Arkansas State Geological Commission Little Rock, Arkansas 501-371-1488		X				X
James Shell Department of Pollution Control and Ecology Water Division Little Rock, Arkansas 501-371-1701		X	X			
David Williams Attorney General's Office Little Rock, Arkansas 501-371-2007		X	X			
Arizona						
Ray Donavan Field Supervisor of Mines Arizona Bureau of Mines University of Arizona Tuscon, Arizona 602-294-1170		X	X		X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Arizona (Cont'd.)						
John Jett Arizona Department of Mineral Resources Phoenix, Arizona 602-271-3791		X	X	X	X	
Joseph Arundale Liaison Officer U.S. Bureau of Mines Phoenix, Arizona		X			X	
Frank Sepulvera Arizona State Mine Inspection Office Phoenix, Arizona 602-271-5971		X	X		X	
Ronald Miller Bureau of Water Quality Control Department of Health Services Phoenix, Arizona 602-255-1252		X	X			
Dr. William Dresher Director, Arizona Bureau of Mines University of Arizona Tuscon, Arizona 602-294-1170		X				X
Dr. Thomas O'Neil Assistant Director, Arizona Bureau of Mines University of Arizona Tuscon, Arizona 602-294-1170		X				X
David Ronald Attorney General's Office Phoenix, Arizona 602-255-3562		X	X			

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
California						
James Connell Director of Mining Engineering W.A. Wahlerand Associates Palo Alto, California 415-968-6250		X				X
Gordon Bunker State Mine Inspector California Division of Industrial Safety San Francisco, California 415-557-2405		X	X			
John McWilliams U.S. Bureau of Mines Sacramento, California 916-440-2417		X	X		X	
Tom Enowa California Water Quality Division Sacramento, California 916-445-7971		X				X
Ed Anton California Water Resources Control Board Sacramento, California 916-322-3583		X	X			

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
California (Cont'd.)						
David Jones National Park Service California 415-556-8220		X	X			
Robert J. Schmitt Stanford Research Institute Palo Alto, California 415-326-6200		X	X			
Colorado						
Paul Russell Denver Mining Research Center Denver, Colorado 303-234-3754	X	X				X
Norman Blake Division of Mines Denver, Colorado 303-839-3401	X	X	X			
David Cole Colorado Mining Associates Denver, Colorado 303-534-1181	X	X			X	
Roger Dewey Skelly and Loy Denver, Colorado 303-233-2445	X	X	X		X	
Peggy Walker Liaison U.S. Bureau of Mines Denver, Colorado 303-234-4144	X	X			X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Colorado (Cont'd.)						
Rodney Knutson Law Firm of Dawson, Knagel, Sherman, and Harward Denver, Colorado 303-893-2900	X	X				X
David Phillips Rocky Mountain Mineral Law Foundation University of Colorado Boulder, Colorado 303-449-0943	X	X			X	
Sharon Metcalf Department of Health Denver, Colorado 303-388-6111	X	X	X			
Will Jones Department of Natural Resources Denver, Colorado 303-839-3611	X	X	X			
Mike Elex Mine Safety and Health (MSHA) Denver, Colorado 303-234-3421	X	X	X			
Rob Williams Environmental Protection Agency Denver, Colorado 303-837-4401	X	X	X			

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
Connecticut						
Dr. Hugo Thomas State Geologist Hartford, Connecticut 203-566-3540		X			X	
Sidney Quarrier Department of Environmental Protection Hartford, Connecticut 203-566-5599		X	X			
Florida						
John Sweeney Liaison Officer U.S. Bureau of Mines Tallahassee, Florida 904-222-6218		X				X
Georgia						
Doss White, Jr. Liaison Officer U.S. Bureau of Mines Atlanta, Georgia 404-221-6204	X	X	X		X	
James Hazlewood Georgia Marble Corporation 404-432-0131	X	X	X			
Sanford P. Darby Department of Natural Resources, Environmental Protection Division Atlanta, Georgia 404-656-4708	X	X	X			

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
Georgia (Cont'd.)						
Mr. T. Michael U.S. Environmental Protection Agency, Region IV Atlanta, Georgia 404-881-2017	X	X	X			
Mr. Robert S. Boman Attorney General's Office Atlanta, Georgia 404-656-3377	X	X	X			
Idaho						
Dr. Samuel Chan University of Idaho Moscow, Idaho 208-885-6111		X				X
Dale R. Ralston Hydrologist University of Idaho Moscow, Idaho 208-885-6111		X		X		
Robert Kinghorn Director, Department of Labor and Industrial Services Boise, Idaho 208-384-3950		X	X			
Frank Sherman Department of Water Resources Boise, Idaho 208-384-2215		X			X	
Jack Richmond Department of Labor and Industrial Services Boise, Idaho 208-384-2327		X			X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
Idaho (Cont'd.)						
Al Murray Bureau Chief, Department of Health and Welfare Boise, Idaho 208-384-2433		X	X			
Warren Felton Attorney General's Office Boise, Idaho 208-384-2400		X	X			
Art Zierold Department of Lands Boise, Idaho 208-384-3569		X	X			
Terry Maley Administrator, Department of Lands Boise, Idaho 208-384-3568		X				X
Steven Alred Department of Water Resources Boise, Idaho 208-384-2215		X				X
Jack Peterson Secretary Idaho Mining Association Boise, Idaho 208-342-0031		X			X	
Dennis Gray Department of Environmental Services Boise, Idaho 208-384-2433		X	X			

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
Illinois						
Russell T. Dawe Department of Mines and Minerals Springfield, Illinois 217-782-6791		X	X			
Charles Flaustas U.S. Environmental Protection Agency Region IV Chicago, Illinois 312-353-2105	X	X	X			
Ronald Bargany Division of Water Resources Springfield, Illinois 217-782-0610	X	X	X			
Lawrence Reische Attorney General's Office Springfield, Illinois 217-782-1090	X	X	X			X
Indiana						
Joseph Snyder Department of Natural Resources, Division of Water Indianapolis, Indiana 317-633-0766	X	X	X			
Larry Cain Department of Natural Resources, Division of Water Indianapolis, Indiana 317-633-0761	X	X	X			
Ralph Clarke Bureau of Mines and Mining Terre Haute, Indiana 812-232-6406	X	X	X		X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Indiana (Cont'd.)						
John Winters Indiana Board of Health Indianapolis, Indiana 317-633-4360	X	X	X		X	
Dr. Earl Bonner Indiana Board of Health Indianapolis, Indiana 317-633-4360	X	X	X			
Jeffrey Feller Department of Natural Resources, Division of Planning Indianapolis, Indiana 317-633-0735	X	X				X
William Miska Liaison Officer U.S. Bureau of Mines Bloomington, Indiana 812-339-6139	X	X			X	
James Ray Department of Natural Resources Indianapolis, Indiana 317-633-0766	X	X	X			
Westly T. Wilson Attorney General's Office Indianapolis, Indiana 317-633-6335	X	X	X			
Iowa						
Renalda Nelson Mines and Minerals Division Department of Soil Conservation Des Moines, Iowa 515-281-5774	X	X			X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
Iowa (Cont'd.)						
Marvin Ross Director, Division of Soil Conservation Department of Mines and Minerals Des Moines, Iowa 515-281-5774	X	X	X		X	
Larry Crane Department of Envirionmental Quality 515-281-8693	X	X				X
Jerry Tonneson Department of Environmental Quality Des Moines, Iowa 515-281-8994	X	X	X			
Steve Balmgarn Planner, Department of Environmental Quality Des Moines, Iowa 515-281-5351	X	X				X
Mike Valde Assistant Attorney General Des Moines, Iowa 515-281-5351	X	X	X			
Kansas						
Larry Brady Geological Survey Lawrence, Kansas 913-864-4991	X	X	X			
Donald Carlson Department of Health and Environment Topeka, Kansas 913-862-9360	X	X	X			

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
Kansas (Cont'd.)						
F. Dale Sayler Industrial Safety Division Lawrence, Kansas 913-296-4386	X	X	X			
Robert McDougal Liaison Officer U.S. Bureau of Mines Topeka, Kansas 913-295-2520	X	X			X	
Mel Gray Department of Health and Environment Topeka, Kansas 913-862-9360	X	X				X
Ken Cassidy Kansas Corporation Commission Topeka, Kansas 913-296-3355	X	X				X
Kentucky						
Elmore Grim Division of Forestry Frankfort, Kentucky 502-564-4496	X	X			X	
Harold Kirkpatrick Director, Department of Mines and Minerals Lexington, Kentucky 606-254-0367	X	X	X		X	
Dick Bielicki Island Creek Coal Company Paintsville, Kentucky 606-789-1201	X	X			X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Kentucky (Cont'd.)						
Tim Salvetti President of the Northern Division of Island Creek Coal Company Paintsville, Kentucky 606-789-1201	X	X			X	
Mr. James Beery Department of Mines and Minerals Lexington, Kentucky 606-254-2126	X	X	X			
Randy Pohren Department of Natural Resources and Environmental Protection Frankfort, Kentucky 502-564-2126	X	X	X		X	
Gene Brandenburg Bureau of Surface Mining Frankfort, Kentucky 502-564-6940	X	X	X			
Rich Jones Bureau of Surface Mining Frankfort, Kentucky 502-564-5576	X	X	X			
William Boyd Liaison Officer U.S. Bureau of Mining Frankfort, Kentucky 502-875-4120	X	X			X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
Kentucky (Cont'd.)						
Rodney Gaines Department For Natural Resources and Environmental Protection Division of Water Resource Frankfort, Kentucky 502-564-2126	X	X	X			
Louisiana						
Owen W. Jones Liaison Officer U.S. Bureau of Mines Baton Rouge, Louisiana 504-389-0374		X	X		X	
Stream Control Commission Baton Rouge, Louisiana 504-342-6363		X	X			
Dwain Broussard Attorney General's Office Baton Rouge, Louisiana 504-342-7013		X	X			
Maine						
Charles Kelloge Department of Environmental Protection Augusta, Maine 207-289-2111		X			X	
Steven Graves Director, Bureau of Water Quality Control Augusta, Maine 207-289-2591		X	X		X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
Maine (Cont'd.)						
Mr. Lester Wood Department of Manpower Affairs Bureau of Labor Augusta, Maine 207-289-3331		X	X			
Henry Mann Attorney General's Office Augusta, Maine 207-289-3051		X	X			
Robert Doule Director and State Geologist Geological Survey Augusta, Maine 207-289-2801		X	X			
Maryland						
Joseph Sutton Liason Officer U.S. Bureau of Mines Washington, D.C. 301-359-3057	X	X			X	
Dr. Kenneth Weaver State Geologist Geological Survey Baltimore, Maryland 301-235-0771	X	X				X
Ken Schmidt Department of Natural Resources Surface Water Permit Section Annapolis, Maryland 301-265-2265	X	X				X

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
Maryland (Cont'd.)						
Harry Buckley Director, Bureau of Mines Westernport, Maryland 301-359-3057	X	X				X
John Griffith Legal Counselor Department of Natural Resources Annapolis, Maryland 301-269-2251	X	X	X			
Henry Stetina Potomac River Basin Commission Annapolis, Maryland 301-340-2661	X	X	X			
Professor Garrett Power University of Maryland School of Law Baltimore, Maryland 301-528-7661	X	X	X		X	
Massachusetts						
Joseph Sennott State Geologist Department of Environmental Quality Boston, Massachusetts 617-727-4508		X	X			
Michigan						
Dr. Allen Johnson Senior Research Geologist Michigan Technological University Houeghton, Michigan 906-487-2600		X		X	X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
Michigan (Cont'd.)						
Esther Middlewood M.E.S.H.A. Lansing, Michigan 517-372-1910		X	X	X	X	
Bill North Department of Labor M.E.S.H.A. Lansing, Michigan 517-372-1910		X			X	
Bob Reed Department of Natural Resources Geological Survey Division Lansing, Michigan 517-373-1256		X		X	X	
Mr. Harry Sorensen Department of Natural Resources Geological Survey Division Lansing, Michigan 517-373-1256		X			X	
Joe Bul Department of Natural Resources Division of Water Quality Lansing, Michigan 906-786-9327		X		X		
Ted Tucker Acting Chief, Department of Natural Resources Lands Division Lansing, Michigan 517-373-1250		X			X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Michigan (Cont'd.)						
Frank Pipp Attorney General's Office Lansing, Michigan 517-373-1110		X	X		X	
Minnesota						
Ron Briggs Liaison Officer U.S. Bureau of Mines Twin Cities, Minnesota 612-725-4535		X			X	
Mike Costello Department of Natural Resources Division of Minerals St. Paul, Minnesota 612-296-4807		X	X		X	
Jim Schoessler Attorney General's Office St. Paul, Minnesota 612-296-3294		X	X		X	
Mississippi						
Owen W. Jones Liaison Officer U.S. Bureau of Mines Jackson, Mississippi 601-969-4208		X				X
Missouri						
Lawrence Casteel Southwest Division Manager St. Joe Mineral Corporation Missouri 314-244,5261		X		X	X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Missouri (Cont'd)						
Dr. Alden Carpender Geochemist and Hard Rock Geologist University of Missouri Columbia, Missouri 314-882-6785		X		X	X	
Richard T. Petrus PEC 412-563-6556		X			X	
James Coyne Peabody Coal Company St. Louis, Missouri 314-342-3628		X		X		
Bill Marbaker Mining Industry Council St. Louis, Missouri 314-635-7308		X	X		X	
Don Davis Director of Inspection Section Department of Labor Industrial Relations Jefferson City, Missouri 314-751-3402		X		X		
Waldemar Dressel Liaison Officer U.S. Bureau of Mines Rolla, Missouri 314-364-3169 or 364-5555		X			X	
John Wright Director, Clayton Missouri Branch 314-726-9500		X			X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Missouri (Cont'd.)						
Dan Lyman Attorney General's Office Jefferson City, Missouri 314-751-3321		X	X		X	
Montana						
Dr. Sidney L. Groff Director and State Geologist Bureau of Mines and Geology Butte, Montana 406-792-8321	X	X	X			
George Krempasky Liaison Officer U.S. Bureau of Mines Helena, Montana 406-449-5297	X	X			X	
Dwain Reber Montana Mining Association Massoula, Montana	X	X				X
James Mockler Montana Coal Council Helena, Montana 406-442-6223	X					X
Fred Shuman Department of Health and Environmental Sciences Helena, Montana 406-449-2406	X	X	X			
Alan Choronister Attorney General's Office Helena, Montana 406-449-2026	X	X	X		X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Nebraska						
Ron Smanse Natural Resources Commission Lincoln, Nebrasks 402-471-2081		X			X	
Bob Wall Chief, Water Pollution Council Division Department of Environmental Control Lincoln, Nebraska 402-471-2186		X	X			
Mr. Raymond Burchett Conservation and Survey Division Lincoln, Nebraska 402-472-3471		X	X	X	X	
Mr. Gerald Vithminas Attorney General's Office Lincoln, Nebraska 402-471-2313		X	X			
Nevada						
Harry E. Springer Nevada Bureau of Mines Carson City, Nevada 702-885-5243		X	X			
Marvin Teveau State Environmental Commission Carson City, Nevada 702-885-4670		X	X			
John Kenneth Jones Exploration Geologist of Nevada Reno, Nevada 702-329-6481		X			X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Nevada (Cont'd.)						
Robert E. Warren Executive Secretary Nevada Mining Association Reno, Nevada 702-323-8975		X				X
Francis E. DuBois State Mine Inspector Carson City, Nevada 702-885-5243		X			X	
James Fraser Nevada - MSHA Spark, Nevada 702-358-0210		X				X
Richard Serdoz State Environmental Commission Carson City, Nevada 702-885-4670		X				X
New Hampshire						
Mr. Theodore Natti Council of Resources and Development Concord, New Hampshire 603-271-2214		X			X	
Glen Stewart Office of State Geologists University of New Hampshire Durham, New Hampshire 603-862-1216		X	X			
William R. Barton Liaison U.S. Bureau of Mines New Market, New Hampshire 603-271-2214		X	X			

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
New Jersey						
Bob Metzger Chief Geologist, New Jersey Zinc Company Ogdenburg, New Jersey 201-827-7121		X		X		
Mike Pustay Director, Department of Labor and Industry Trenton, New Jersey 609-292-2121		X	X		X	
New Mexico						
Joe Longacre Office of State Mine Inspectors Bureau of Mines and Mineral Resources Albequerque, New Mexico 505-842-3055	X	X	X			
Maxine Good Environmental Improvement Agency Santa Fe, New Mexico 505-827-5271	X	X			X	
Bruce Garber New Mexico Legal Council Santa Fe, New Mexico 565-827-5271	X	X	X			
Arnold Emery State Geologist State Bureau of Mines Santa Fe, New Mexico 505-842-3055	X	X	X			
	X	X			X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
New Mexico (Cont'd.)						
Herman Sheffer Liaison Officer U.S. Bureau of Mines Santa Fe, New Mexico 505-988-6624	X	X			X	
New York						
John Dragonetti Department of Environmental Conservation Albany, New York 518-457-7480		X	X		X	
Sal Pagano Department of Water Resources Albany, New York 518-457-3967		X	X		X	
John Frisco Environmental Protection Agency New York City, New York 212-264-2676		X	X			
S. Leonard Wall Department of Labor Council Albany, New York 212-488-6657		X	X			
North Carolina						
Lawrence Shirley Liaison Officer U.S. Bureau of Mines Raleigh, North Carolina 919-755-4166		X			X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
North Carolina (Cont'd.)						
Charles Gardner Chief, Land Quality Section of the Department of Land Resources (DNR) Raleigh, North Carolina 919-733-4574		X	X	X		
Harry Peek Department of Natural and Economic Resources Environmental Management Division Raleigh, North Carolina 919-733-2594		X			X	
Aaron C. Turnage Department of Natural and Economic Resources Environmental Management Division Raleigh, North Carolina 919-733-5291		X	X	X		
North Dakota						
Mr. Erling Broftmen Geologic Survey Grand Forks, North Dakota 701-777-2231		X	X			
Dean Petersen Public Service Commission Bismaur, North Dakota 701-224-2400	X		X			
Jim Asse Liaison U.S. Bureau of Mines Bismark, North Dakota	X	X			X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
North Dakota (Cont'd.)						
Owen Anderson Attorney General's Office Bismark, North Dakota 701-224-2802	X	X	X			X
Ohio						
Ronald Hill U.S. Environmental Protection Agency Cincinnati, Ohio 513-684-4410	X				X	
Moid M. Ahmad Ohio State University Columbus, Ohio 614-594-6650	X			X	X	
Heury Ciechomski Ohio Department of Mines Columbus, Ohio 614-466-4240	X	X	X	X		
Mr. Richard Witt U.S. Environmental Protection Agency Columbus, Ohio 614-466-2390	X	X	X		X	
Joe Taylor Ohio Attorney General Columbus, Ohio 614-466-2766	X	X	X		X	
Steve Hamlin U.S. Environmental Protection Agency Logan, Ohio 614-385-8501	X	X	X			

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Oklahoma						
Robert H. Arndt Water Resource Board Oklahoma City, Oklahoma 405-231-4521	X	X	X	X	X	
Ward Padgett Chief Inspector, State Department of Mines Oklahoma City, Oklahoma 405-521-3859	X	X	X		X	
Jerry Wood Water Resource Board Oklahoma City, Oklahoma 405-521-3945	X	X	X		X	
Edward Parker Water Resource Board Oklahoma City, Oklahoma 405-521-3945	X	X	X			
Jeff Weers Attorney General's Office Oklahoma City, Oklahoma 405-521-3921	X	X	X			
James Barnett Water Resource Board Oklahoma City, Oklahoma 405-271-2555	X	X	X			
Oregon						
Andrew Fergus U.S. Bureau of Mines Field Office Albany, Oregon 503-967-5844	X	X	X		X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Oregon (Cont'd.)						
John M. West Liaison U.S. Bureau Of Mines Salem, Oregon 503-399-5755	X	X			X	
Cliff Allison Department of Labor, Division of Rules and Regulations Albany, Oregon 503-378-3341		X	X			
Ed Quan Division of Water Quality Portland, Oregon 503-229-5696		X	X		X	
Ken Ashbaker Division of Water Quality Portland, Oregon 503-229-5325		X	X			
Pennsylvania						
James Boyer Bitumiuous Coal Research Bureau Monroeville, Pennsylvania 412-327-1600	X			X		
John W. Foreman Gwin, Dobson and Foreman, Inc. Altoona, Pennsylvania 814-943-5214	X			X	X	
Bud Fredrick and Don Fowler Department of Environmental Resources Harrisburg, Pennsylvania 717-787-4345	X		X	X	X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
Pennsylvania (Cont'd.)						
Ray Orowetz Pulman-Swindell, Inc. Pittsburgh, Pennsylvania 412-562-7000	X			X		
Murice Deul U.S. Bureau of Mines Monroeville, Pennsylvania 412-892-2400	X			X	X	
Jack Pence Consolidated Coal Company Bethel Park, Pennsylvania 412-831-4000	X			X	X	
Carolyn Petrus H.R.B. Singer, Inc. State College, Pennsylvania 814-238-4311	X					X
Dan Sweeney Environmental Protection Agency Philadelphia, Pennsylvania 215-597-8821	X		X			
Ernie Geoninetti Department of Environmental Resources Harrisburg, Pennsylvania	X	X	X			
Tom Alexander Department Environmental Resources McMurray, Pennsylvania 412-941-7100	X	X				X

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Pennsylvania (Cont'd.)						
Doug Blazey Legal Council Bureau of Litigation Department of Environmental Resources Harrisburg, Pennsylvania 717-787-7060	X	X	X			
Ted Bioni Mine Safety and Health Administration, District II Pittsburgh, Pennsylvania 412-621-4500	X					X
Frank Miller Republic Steel Uniontown, Pennsylvania 412-438-2587	X			X	X	
George Medsger Republic Steel Uniontown, Pennsylvania 412-438-2587	X			X		
Robert Witt U.S. Steel Uniontown, Pennsylvanis 412-438-3511	X				X	
Frank Neely U.S. Steel Uniontown, Pennsylvania 412-438-3511	X					X
Charles E. Taylor, Jr. Manager-Grace and Cornwall Mines Bethlehem Mines Corporation Philadelphia, Pennsylvania 215-694-5743		X		X		

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Pennsylvania (Cont'd.)						
Dr. Donald Watson Slippery Rock State College Slippery Rock, Pennsylvania 412-794-2510	X	X		X	X	
Corneluis J. Hannigen Chief Engineer Bethlehem Mines Corporation Bethlehem, Pennsylvania 215-694-2429	X	X				X
Al Molinsky Department of Environmental Resources Ebensburg, Pennsylvania 814-472-9666	X				X	
Ronald Stingelin HRB Singer, Consultants State College, Pennsylvania 814-238-4311	X					X
John Wakelee Chief, Environmental Division Michael Baker Consultants Beaver, Pennsylvania 412-495-7711	X	X		X		
Bill Hoyle Eastern Association Coal, Incorporation Pittsburgh, Pennsylvania 412-288-8205	X			X	X	
John J. Hunter State Mining Inspector Irwin, Pennsylvania 412-863-0363	X					X

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
Pennsylvania (Cont'd.)						
Connely Crass Bethlehem Mines Corporation Morgantown, Pennsylvania 215-286-5011	X				X	
Knoll Moebs U.S. Bureau of Mines Monroeville, Pennsylvania 412-892-2400	X			X	X	
John Mores Turtel Creek Watershed Association Pittsburgh, Pennsylvania 412-256-2433	X			X	X	
Dr. Harold L. Lovell Department Head Mining and Engineering Department Penn State University State College, Pennsylvania 814-865-4700	X			X	X	
Major C.P. Ahnell, Jr. Army Corp of Engineers Pittsburgh District Pittsburgh, Pennsylvania 412-644-6878	X				X	
Walter J. Vincinelly Commissioner, Office of Deep Mine Safety Department of Environmental Resources Harrisburg, Pennsylvania 717-787-1376	X	X	X	X	X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
Rhode Island						
Carleton A. Maine Department of Environmental Management Providence, Rhode Island 401-277-2234	X	X	X			
Bill Bonn Department of Environmental Management Providence, Rhode Island 401-277-2234		X		X		
South Carolina						
Hewson Lawrence U.S. Bureau of Mines Columbia, South Carolina 803-765-5561		X	X	X		
Morry Wood Land Resources Conservation Commission Regulatory Services Columbia, South Carolina 803-758-2823		X	X	X		
South Dakota						
Jerry Ortbahm South Dakota School of Public Lands Pierre, South Dakota 605-773-3303	X	X	X	X		
Dwane Murphy Department of Environmental Protection Pierre, South Dakota 605-773-3303	X	X	X		X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
South Dakota (Cont'd.)						
Larry Kyte Assistant Attorney General Pierre, South Dakota 605-773-3805	X	X	X		X	
Bill Harris South Dakota Department Natural Resources Pierre, South Dakota 605-773-4160	X	X	X	X	X	
Ralph Tibble Assistant Manager Lead, South Dakota 605-584-1020	X	X		X		
Tennessee						
Robert May U.S. Bureau of Mines Nashville, Tennessee 615-525-9336	X	X	X			
Houston Payne State Division of Mines Knoxville, Tennessee 615-525-9336	X	X	X			
Clay Carter Division of Water Quality Control Nashville, Tennessee 615-741-2275	X	X	X			

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Tennessee (Cont'd.)						
Shaw Hickerson Tennessee Department of Conservation Nashville, Tennessee 615-741-3043	X	X	X			
Texas						
Sara Watson Liaison Officer U.S. Bureau of Mines Austin, Texas 512-397-5781	X	X	X		X	
Cora Robins Surface Mining and Reclamation Department Austin, Texas 512-475-6534	X	X	X		X	
Jerry Mulligan Water Resources Department Austin, Texas 512-475-2041	X	X	X			
Utah						
Jack Christianson Director Utah Mining Association Salt Lake City, Utah 801-364-1874	X	X			X	
Ron Daniels Utah Oil, Gas and Mining Mine Safety Salt Lake City, Utah 801-533-5771	X	X	X	X		

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
Utah (Cont'd.)						
Cleon Feight Utah Oil, Gas and Mining Salt Lake City, Utah 801-533-5771	X	X	X			
Steve McNeil Bureau of Environmental Health Salt Lake City, Utah 801-533-6146	X	X	X			
Utah Attorney General's Office Salt Lake City, Utah 801-533-5261	X	X	X		X	
Vermont						
Charles A. Ratte State Geologist Agency of Environmental Conservation Montpelier, Vermont 802-828-3357		X	X	X	X	
David Glough Vermont Water Quality Division Monpelier, Vermont 802-828-2761		X	X			
Meridith Wright Attorney General's Office Montpelier, Vermont 802-828-3171		X	X		X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Virginia						
Frank Linkous Division of Mines and Quarries Big Stone Gap, Virginia 703-523-0335	X	X	X			
William Roller Division of Reclamation Big Stone Gap, Virginia 703-523-2925	X	X	X			
Mr. Andrew Bailey U.S. Geological Survey Mining Office Herndou, Virginia 703-860-7506	X	X	X			
Virginia Water Quality Control Board Richmond, Virginia 703-628-5183	X	X	X			
Mr. Kyle Attorney General's Office Richmond, Virginia 804-786-2071	X	X	X			
Tom Leshendok U.S. Geological Survey 703-860-7506	X	X	X			
Washington						
Carl Mote Northwest Mining Association Spokane, Washington 509-624-1158	X	X	X	X	X	
Vaughn Livingston Washington Geology and Earth Resources Division Olympia, Washington 206-753-3560	X	X		X	X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Washington (Cont'd.)						
Herb Babitzke Liaison Officer U.S. Bureau of Mines Olympia, Washington	X	X	X			
George Houck Washington Water Resources Department Olympia, Washington	X	X	X			
Jim Sullivan Department of Labor and Industry Olympia, Washington 206-753-3560	X	X	X	X		
Mike Tardiff Attorney General's Office Portland, Washington 206-753-6370	X	X	X			
Washington D.C.						
Matt Jarrett Environmental Protection Agency Washington D.C. 202-426-4617	X	X	X			
Ron Kirby Environmental Protection Agency Washington, D.C. 202-426-7770	X	X	X			
Dave Shedroff Legal Council Environmental Protection Agency Washington, D.C. 202-755-8731	X	X	X			

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Washington, D.C. (Cont'd.)						
Tom Rigs Bureau of Indian Affairs Washington, D.C. 202-343-3722	X	X	X			
Don Wilson Office of Surface Mining Washington, D.C. 202-343-5335	X	X	X			
John Demchech Appalachian Regional Commission Washington, D.C. 202-673-7984	X			X	X	
Tom Mascolino Legal Council Mine Safety and Health Administration Washington, D.C. 202-235-1153	X	X	X			
Bob Uram Legal Council Solicitors Office Department of Interior Washington, D.C. 202-343-4803	X	X	X			

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
West Virginia						
Albert Jordan West Virginia Department of Mines Charlestown, West Virginia 304-348-2051	X	X	X		X	
Merle McManus Mine Safety and Health Administration Morgantown, West Virginia 304-599-7277	X	X	X	X	X	
Ed Pash Fish and Wildlife Service Harpers Ferry, West Virginia 304-535-6311	X	X			X	
Allen Roy Allied Chemical Corporation Beckley, West Virginia 304-255-4401	X	X		X	X	
Nick Johnson Attorney General's Office Charlestown, West Virginia 304-348-2522	X	X	X			
Wisconsin						
Ron Briggs Liaison Officer U.S. Bureau of Mines Twin Cities, Wisconsin 612-725-4535		X	X		X	
Ed Bull Department of Industry and Human Relations Mine Safety Unit Madison, Wisconsin 608-266-3151		X	X			

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGU-LATIONS	CASE STUDY	REFERRAL	NO INFOR-MATION
Wisconsin (Cont'd.)						
Gordon Hecreid Mine Impact Board Madison, Wisconsin 608-266-1818		X				X
Wyoming						
Alan W. Shafer State Inspector of Mines Rock Springs, Wyoming 307-362-5222	X	X	X			
Charles Koch Liaison Officer U.S. Bureau of Mines Cheyenne, Wyoming 307-778-2228	X	X	X			
Bill Budd Wyoming Mining Association Cheyenne, Wyoming 307-635-0331	X	X		X		
Sterling A. Case Assistant Attorney General Cheyenne, Wyoming 307-777-7841	X	X	X		X	
John Wagner Environmental Quality Department Cheyenne, Wyoming 307-777-7781	X	X	X			
Canada						
Richard Bray Consultant Kingston, Ontario 613-542-4363		X			X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
Canada (Cont'd.)						
Dr. Thomas Mohide Ministry of Natural Resource Toronto-Ontario, Canada 416-965-1328		X		X		
Lorne Brooks Miranda Mines-Gego Division Manitouwadge, Ontario 807-826-3211		X	X	X	X	
International Contacts						
Mr. Chadworth Harrad National Coal Board United Kingdom 011-44-1-235-2020			X	X		
William Keyes Area Chief, Western Europe Bureau of Mines International Data and Analysis Washington, D.C. 202-632-5047						X
Joseph Huvos Liaison, West Germany Bureau of Mines International Data and Analysis Washington, D.C. 202-632-5047						X
Tatiana Karpinsky Liaison, Poland Bureau of Mines International Data and Analysis Washington, D.C. 202-632-5060				X	X	

CONTACT	SUBJECT OF REQUEST		RESPONSE			
	COAL MINES	METAL, NON-METAL MINES	REGULATIONS	CASE STUDY	REFERRAL	NO INFORMATION
International Contacts (Cont'd.)						
Charles Wyche Liaison, Australia Bureau of Mines International Data and Analysis Washington, D.C. 202-632-5052				X	X	
Miller Ellis Liaison, South Africa Bureau of Mines International Data and Analysis Washington, D.C. 202-632-5065						X